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THE HEALTH OF OUR WATER

Toward
sustainable
agriculture
in Canada

Canada

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sustainable
agriculture
in Canada

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and
L.J. Gregorich
(editors)

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Foreword

Many systems in our world are dependent on water—natural systems, such as biological communities, and human systems, including towns and cities, industry, and agriculture. All these users have an effect on the water resource, and all have an interest in issues of water quantity and water quality. But because this resource is relatively plentiful in Canada, it may be taken for granted and used without adequate care.

Farmers are sensitive to water issues, because their crops and animals need sufficient quantities of good-quality water. In most areas in Canada, rainfall supplies crops with needed water. However, in many areas water also comes from surface runoff, watercourses such as streams and rivers, or groundwater sources. Too much or too little water, or water at the wrong time, decreases agricultural production. The extremes, namely droughts or floods, can have disastrous effects. Farmers and other rural residents and industries must share this resource with fish and wildlife, and with those who enjoy the many recreational benefits of our rural landscape.

The water resource is affected naturally over time in many ways. Erosion alters the constituents carried by water. Leachates reaching groundwater change its chemical composition. Also, climate change causes new runoff patterns. Many of these long-term changes can be speeded up or made worse by human activity. For example, the quantity or timing of supply may change at critical times of the year; or water may be contaminated by chemicals or living organisms, and its usefulness diminished. Such changes may be subtle and go unnoticed at first.

It is important that the health of our water be monitored so we can understand the changes taking place. Only then can we take corrective actions as needed. *The Health of Our Water* is an important document that summarizes much useful information on the state of rural water in Canada. Among other things, it shows that water quality is intimately connected to soil quality, improving where soil conservation practices are used.

With contributions from almost 100 authors, this book draws on the experience and knowledge of experts from a wide range of fields—agronomy, soil science, agricultural engineering, agricultural policy, hydrogeology, meteorology, water chemistry, aquatic biology, and wildlife conservation, among others. This diversity of authorship ensures a balanced treatment of the subject, with fair consideration of the many views held by various stakeholders. Using a variety of research findings and case studies, *The Health of Our Water* provides a broad picture of water quantity and quality in Canada as they are affected by agriculture, and as they affect agriculture itself. It will be useful in identifying issues for immediate action and will also serve as a benchmark against which to measure future changes.

This book bolsters Canada's international reputation of being in the vanguard of research and reporting on environmental interests. It is a welcome addition to the pool of information on natural resources and the environment that is available to farmers, the non-farming public, politicians, government agencies, and educational institutions.

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Preface

Water is essential for all living creatures and is an important component of countless human activities. Canada has an extensive reserve of freshwater. Yet water may be scarce in some places or of unsuitable quality for some purposes. Growing human demands for water are sure to add further constraints on this resource. And changes in natural forces, such as potential climate change, can also affect the supply and distribution of water. It is therefore essential that we examine the state of water quantity and quality in Canada and devise ways to manage our water resources sustainably.

An interest in issues of water quantity and quality is a vital component of the expanding environmental agenda of agriculture in Canada. This interest was clearly enunciated in the 1990 *Report to Ministers of Agriculture* by the Federal-Provincial Agriculture Committee on Environmental Sustainability, which emphasized the importance of these issues for the sustainability of the agri-food sector. Following this, Agriculture and Agri-Food Canada (AAFC) developed its sustainable development strategy, *Agriculture in Harmony with Nature—Strategy for Environmentally Sustainable Agriculture and Agri-Food Development in Canada*. This strategy promotes environmental and resource stewardship, with an emphasis on water quality, both on and off the farm. The business plan of AAFC's Research Branch also calls for responsible use of natural resources, including the maintenance of surface- and ground-water quality.

In the past, agricultural production was less considerate of the natural resources on which it depends. Today, good stewardship begins with knowing the state of our resources. It then moves on to develop ways to maintain or improve this state. In keeping with this goal, AAFC has now completed a project to develop a set of agri-environmental indicators. These indicators are useful in assessing the current state of agricultural resources and examining trends in the environmental performance of agriculture. Two of the indicators relate to the risk of water contamination by agriculturally derived substances and thus to the threat to water quality

resulting from agricultural production. The findings of this project, reported in *Environmental Sustainability of Canadian Agriculture—Report of the Agri-Environmental Indicator Project*, provide much evidence of a growing stewardship ethic in the agri-food sector and a greater use of conservation farming practices than was the case 15 years ago. They also point to geographical areas and farming modes that need further attention as we work toward a greater environmental sustainability in Canadian agriculture.

The Health of Our Water joins *The Health of Our Soils* and *The Health of Our Air* to complete a series of publications that show how agriculture interacts with our natural resources. However, the assurance of an adequate supply of clean water is essential not only for agriculture, but also for human health, ecosystem integrity, and the viability of many economic activities. Consequently, water issues are the focus of research and policy making in many other federal departments, including Environment Canada and Health Canada, as well as other levels of government. Thus, unlike its companion books, and as a result of the nature of water research in Canada, *The Health of Our Water* does not mainly report on AAFC research but instead draws widely from sources throughout the country.

This book carries the State of the Environment (SOE) reporting symbol, because it satisfies the guidelines for the federal government's SOE reporting program. The two key purposes of SOE reports are to foster the use of science in policy- and decision-making and to report to Canadians on the condition of their environment. *The Health of Our Water* meets SOE reporting requirements by providing an easily understood overview of an important environmental issue for the non-scientist; examining the key trends of the water issue; discussing links with other issues; and describing the efforts of government, industry, and others to address the water issue and make progress toward environmental sustainability.

We are pleased to present this report and anticipate that it will be useful in the hands of our many interested partners as we continue to work

toward the goals of environmental sustainability in Canada, particularly as they relate to agriculture.

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Executive Summary

Sustainable agriculture cannot be achieved without the wise stewardship of our water resources. This document summarizes what is currently known about the state of water resources in the agricultural areas of Canada.

It does so by

- describing water resources in rural areas and the way in which they are used
- considering the concepts that underlie the assessment of water quality, and then examining the quality of surface water and groundwater in relation to agricultural activities
- discussing the major water-related ecological issues that have resulted from the co-existence of agriculture and natural ecosystems in the rural environment
- looking at ways in which the availability and quality of water can be optimized for the various competing users
- explaining ways in which excess water can be managed to improve drainage and minimize flooding
- discussing the limitations that water availability and quality place on the expansion of agricultural and other development in rural areas.

Canada's rural water resources

Water is available in rural areas in a brief portion of its natural cycle from the atmosphere to the earth's surface and back again. Canada's variable climate and terrain results in a wide variety of moisture conditions across the country, from humid maritime zones on the west and east coasts to the semi-arid regions of interior British Columbia and the Prairies. Rural economies rely on a combination of rainfall and snowmelt, surface water, and groundwater. The driest regions require irrigation to maintain productive agriculture, whereas improved drainage is needed in the wettest regions to be able to cultivate fields. Groundwater in some aquifers, especially in the Prairies, is of naturally poor quality and may be unsuitable for human drinking or irrigation. To provide water when needed, surface water is often stored in reservoirs or dugouts and is sometimes diverted from one area to another. Where waters cross provincial or international boundaries,

agreements are in place governing flow rates and quality.

Water use

Water is needed by all living organisms. It plays an important part in many natural and human-run processes and is essential in countless physical and chemical reactions. Water from precipitation and snowmelt is used directly by crops but, to meet the needs of livestock, farmsteads, households, and rural industries, water is withdrawn from surface and subsurface sources. It is also withdrawn from these sources to irrigate crops in dry regions and, in dry years, high-value crops in other regions. Water is used in livestock production mainly for animal drinking, but also for cleaning facilities and equipment and for diluting manure. Nationally, agriculture withdraws a relatively small amount of water (9%) compared with thermal power generation (63%) and manufacturing (16%). However, it consumes much of what it uses, returning less than 30% to sources from which it can be withdrawn by others. Most farms and rural residents are responsible for their own water supply. Their household water use is similar to that of city dwellers, but during dry periods rural residents are usually more quickly affected by water shortages. Other rural users of water include small towns and villages; the mining, oil and gas industry; aquaculturists; and recreational users. Natural uses, such as fisheries and wildlife habitat, are also important.

Understanding water quality

The definition of good quality water depends on the intended use of the water and the acceptable risk associated with known or potential contaminants. Most water quality guidelines are based on chemical concentrations or the numbers of organisms present. A more holistic approach considers all properties of water—physical, chemical, and biological, and their combined effects. National programs to monitor water quality have been greatly reduced in recent years, as have programs operated by many provincial governments. Monitoring is now most often

carried out cooperatively among several partners, including governments at various levels, user groups, and universities, which focus on specific watersheds or problems. Although agricultural contributions to declining water quality may be significant, they can be difficult to measure because of the nature of farming and the diversity of land, climate, and farming practices across the country. Agriculture itself depends on the availability of good-quality water and may risk impaired production if this resource is threatened.

Surface water quality

Soil conservation practices adopted over the past 15 to 20 years have reduced soil erosion by wind and water and thus the amount of soil moving into waterways. As sedimentation is reduced, so too is the movement into water of substances attached to soil particles, such as phosphorus, pesticides, and bacteria. The amount of sediment entering surface water from farmland is lowest in the Prairies and highest in the potato-growing areas of the Atlantic provinces. Nitrogen seldom reaches toxic levels in surface waters but, together with phosphorus, may cause eutrophication. Concentrations of nutrients in surface water exceed water quality guidelines in some intensively farmed areas where large quantities of manure and fertilizer are used. Pesticides enter surface water in runoff and by atmospheric deposition. Pesticide concentrations are rarely measured at levels that exceed guidelines for drinking water. Guidelines for irrigation and for the protection of aquatic life are sometimes exceeded. Contamination by agriculturally derived bacteria is common. Bacteria numbers are generally elevated in runoff from manure-treated fields, although their abundance in surface waters has not been directly related to livestock density. Heavy metal contamination of surface waters derives mainly from natural sources and has not been reliably linked to agricultural practices, including land application of sewage sludge.

Groundwater quality

Agriculture's main environmental effect on groundwater quality is through contamination by nitrate. Nitrate is present in nearly all groundwater underlying agricultural land, but usually at levels below the *Guidelines for Canadian*

Drinking Water Quality. Concentrations are usually highest in areas of intensive production of crops with high nitrogen needs, intensive livestock production, permeable soils, and irrigated agriculture or heavy rainfall. In well water surveys across the country, the proportion of wells with nitrate concentrations that exceed Canadian drinking water quality guidelines ranges widely (from about 1 to 44%). Comparison with earlier data in Ontario and Alberta suggests that nitrate concentrations in wells have not changed markedly over the past 40 to 50 years. A similar range in the number of wells contaminated with bacteria has been found. In Ontario, however, comparisons with earlier data suggest that the incidence of bacteria in well water has almost doubled there over the same period. Well contamination by nitrate and bacteria is often the result of faulty well construction. It may derive from either point sources, such as leaky septic fields or open manure piles, or nonpoint sources, such as fields receiving manure and fertilizer. Pesticides are found in groundwater in most areas where they are used, but nearly always at concentrations well below guidelines.

Ecological issues

The effects of agriculture on aquatic ecosystems are less well documented than its effects on the quality of surface water and groundwater. These ecological issues are best viewed in the context of the watershed. A watershed is a dynamic system that includes the area of land delineated by the drainage basin, its aquatic components (streams and rivers, agricultural drains, lakes and ponds, riparian zones, and wetlands), and its plant and animal life. Agricultural practices often interface with the aquatic components of a watershed and always have some effect. These effects, which can be positive as well as negative, include altering wildlife habitat, the physical nature of waterways, and water quality. These changes in turn affect the structure and stability of biological communities, often reducing biodiversity. On the other hand, irrigation development in dry regions sometimes introduces aquatic habitat into areas that otherwise have very little. Numerous conservation projects have been undertaken in Canada to restore and improve riparian and aquatic habitat, including work on wetlands and agricultural drains. Enhancement measures not only benefit wildlife, but also in many cases improve the

quality of water used on the farm and add to the esthetic appeal of rural landscapes.

Protecting water quality

All rural residents share responsibility for protecting water quality. Farmers can help to improve water quality by controlling runoff and erosion, improving the management of agricultural inputs and wastes, and making use of buffer zones and shelterbelts. Practices to protect water quality are often the same ones proven successful in promoting soil conservation. The agriculture industry is becoming more environmentally sustainable by working with government and other agencies to develop guidelines and codes that define acceptable agricultural practices, encourage the adoption of environmental farm plans, and, in some cases, offer peer advice on resolving nuisance or pollution complaints. Whole communities are addressing water quality concerns by working at the watershed level. Government responsibility for protecting water quality related to agriculture includes education and training, policy and programs that target areas of intensive crop and livestock production, and regulation.

Maintaining reliable water supplies

Drought is a significant threat to the water supply in the Prairies and Ontario. With possible climate change and increasing trends in population, urbanization, and consumptive use, the impacts of drought can only become more serious. Year-round water supplies are maintained using storage reservoirs and dugouts, particularly in the drier parts of the country. Sustainable use of groundwater depends on withdrawing water at rates that do not exceed recharge. Water management in Canada has traditionally focused on supplies. As competition for this resource grows, demand management tools are expected to achieve more-efficient water use. This approach requires an understanding of the full costs of providing water and disposing of wastewater; using alternative technologies, practices, and processes that support more-efficient water use; and educating water users.

Managing excess water

Artificial drainage has allowed many areas of Canada to be brought into profitable agricultural

production, including areas of highly productive organic soils. Good drainage improves plant growth and yields, helps reduce soil salinity, and allows farmers a wider selection of crops and a longer growing season. Surface drainage systems (a network of ditches) result in the loss of some farmable land and may increase the risk of soil erosion and contribute to declining water quality. Subsurface systems (tile drains) contribute to water pollution through leaching of nitrate and pesticides from soil into streams. Drainage systems can alter the environment by draining wetlands, removing riparian zones, increasing runoff, and changing a region's hydrology. Proper design and maintenance of drainage systems may alleviate some of these effects, but lost riparian and wetland systems are often difficult to replace. On-farm drainage systems are not able to handle large volumes of stormwater received from developed land. Properly designed regional drainage systems may be needed to protect lowland agricultural areas. Even so, damage from major floods cannot always be prevented.

Limits on rural growth related to water

Competition for water among users is expected to grow as water supplies fall short of increased demand, giving rise to conflict in some cases. Agriculture's chief competitors for water supplies are thermal power generation, manufacturing, and municipal water use. Wildlife habitat and fisheries are other important uses of water that must be protected. Drought often limits agricultural production in the semi-arid part of the Prairies and sometimes in other areas. Droughts may become more frequent and severe as a result of global warming. The availability of water for expanding both irrigated agriculture and large-scale livestock production, especially in western Canada, may also be limited. Groundwater, where available, is not always of suitable quality for these types of farming. Expansion of intensive livestock operations may be curbed by concerns for the impact of manure on water quality. Environmental liability is an issue of growing concern to farmers. Economic and environmental policies to protect water quality may limit agricultural growth. The technologies needed to improve environmental performance are not all now available or affordable for farmers.

1. Introduction

D.R. Coote and L.J. Gregorich

Water is needed by all living organisms—plants use it in photosynthesis, humans and other animals drink it, and aquatic plants and animals live in it. Water also plays an important part in many natural and human processes and is a critical component of countless physical and chemical reactions. It also supports many economic activities. Yet freshwater is so common and so abundant in Canada, that we rarely give it a thought—that is, until our water supply is threatened or water becomes less fit for our use.

Only so much water exists in the world. In fact, water hasn't changed in amount or nature for millions of years. It just keeps cycling and recycling from atmosphere to earth and back again. Freshwater makes up less than 3% of the earth's total water resources. Because freshwater is so limited and plays such a key role in world health, economies, and environmental stability, we must conserve it and use it in a sustainable manner.

Agriculture's dependence on water

Although agriculture is not Canada's largest user of water, it is the largest consumer. This means that agriculture removes a good deal of water from the landscape, tying it up in agricultural products or evaporating it back into the air, rather than returning it to streams or groundwater.

Agriculture depends on a reliable supply of good-quality water for many farm uses. These include

- growing crops
- watering livestock
- cleaning farm buildings
- supplying water for domestic use.

Without an adequate supply of water of sufficient quality, the economies and ecosystems of the rural landscape would decline and eventually cease to function. Some parts of Canada, such as Ontario, Quebec, and the Atlantic provinces, usually receive enough water from rainfall and snowmelt to meet their farming needs. Drier



Irrigating crops



Watering livestock

areas, such as portions of Manitoba, Saskatchewan, Alberta, and British Columbia, depend on *irrigation* to supply water for crops, at least during very dry summers.

Agriculture's effects on water

Technological advances over the past 50 years have allowed agriculture to become more productive. Farms have become larger and more mechanized, using *fertilizers* and *pesticides* to maintain production levels.

Many farming practices have contributed to some degree of environmental degradation, including the decline of water quality. Some have promoted *erosion* and *leaching*, which carry potential pollutants from farmland into surface waters and groundwater. The main pollutants of water coming from farmland are *sediment*, *nutrients* (especially *nitrogen* and *phosphorus*), *pesticides* (including *insecticides*, *herbicides*, and *fungicides*), *bacteria*, and *salts*. The presence of these substances can make water unfit for other uses, both by humans and wildlife. The quality of freshwater resources is the first to be affected by agriculture. However, the impact is also felt in



Using water in the home

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some estuarine, coastal, and marine waters that receive affected freshwater.

Agriculture can also change the physical presence of water in a landscape through, for example, the construction of dams and reservoirs; distribution of irrigation water; drainage of wet soils, including *wetlands*; and *sedimentation* of streams and lakes. Such changes not only alter the esthetic appearance of the countryside, but also may affect wildlife habitat and give rise to conflict with other users of water.

Sustainable agriculture

Sustainable agriculture is a way of farming that can be carried out for generations to come. This long-term approach to agriculture combines efficient production with the wise stewardship of the earth's resources. It is hoped that, over time, sustainable agriculture will

- meet human needs for food and fibre
- protect the natural resource base and prevent the degradation of water, soil, and air quality, and biodiversity
- use *nonrenewable resources* efficiently
- use natural biological cycles and controls
- assure the economic survival of farming and the well-being of farmers and their families.

The concept of sustainable agriculture acknowledges that agriculture, although an

important user of water, is one of many users and must share Canada's water resources. It also recognizes that agriculture must be carried out in a way that neither contributes to water pollution nor threatens the health of aquatic ecosystems.

The health of Canada's rural water

In looking at the health of Canada's rural water, there are two main issues—*water quality* and *water quantity*. According to recent public opinion polls, the first is the most pressing environmental issue in Canada today. Questions that must be asked regarding water quality include:

- What are the best indicators of water quality?
- How can these indicators best be measured?
- Are there particular areas of concern in Canada?
- How can we reverse any decline in water quality caused by agriculture?

The second issue, water quantity, relates to the reliability of water supplies. Questions arising from this issue include:

- Is there enough water to go around?
- If not, then who gets the water and who does not?
- How can the amount of water (including excess water and flooding) be managed more efficiently?
- What will be the effect of global warming on water supplies?

Objectives of this report

Growing concentrations of both people and livestock, rising world demands for food, and conflicting uses of water resources are among the issues that call for good decision making when it comes to using our water resources wisely and well. Everyone—farmers, the Canadian public, and government and industry decision makers—all make better decisions about how to act when they have good information.

This report presents an overview of information that is currently available on the subject of

The importance of agriculture in Canada

Productive agricultural land brought many settlers to this country. In Canada's early years, agriculture employed more than 80% of the population. Today only 3% of Canadians are directly occupied in the business of farming, but the agri-food sector employs about 15% of the population.

Farms generated more than \$28 billion in sales in 1998. As a result of our extensive and efficient agriculture, food is plentiful and costs about 14% of the average person's disposable income, making our food among the best and least expensive in the world. As well, about 43% of our agricultural production is exported, contributing in an important way to Canada's positive international trade balance.

Source: Agriculture and Agri-Food Canada, 1999

some estuarine, coastal, and marine waters that receive affected freshwater.

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Growing concentrations of both people and livestock, rising world demands for food, and conflicting uses of water resources are among the issues that call for good decision making when it comes to using our water resources wisely and well. Everyone—farmers, the Canadian public, and government and industry decision makers—all make better decisions about how to act when they have good information.

This report presents an overview of information that is currently available on the subject of

agriculture and rural water and provides a benchmark against which to measure progress in the future. Its objectives are to define healthy rural water, describing factors that contribute to such a condition, and to assess the health of Canada's rural water,

- identifying and describing the main issues and problems
- assessing its present status
- suggesting ways to improve it
- predicting future trends.

Reading and using the report

The report is presented in four parts. Chapters 2, 3, and 4 provide background material on the water cycle, water supplies in Canada, agricultural and other rural uses of water, and the issues related to water quality. These chapters set the scene and equip the reader to better understand the technical information that follows.

Chapters 5, 6, and 7 describe what is currently known about the health of Canada's rural waters, both surface water and groundwater, and the implications for natural ecosystems. Chapters 8, 9, and 10 describe responses to the various issues of water quality and water quantity, citing farming practices and regulatory tools, among other measures. Chapter 11 discusses how the growth of agriculture may be limited by issues related to water and where we might go from here. The report ends with concluding remarks.

No program currently exists in Canada to systematically monitor the health of rural water throughout the country. It was therefore necessary to evaluate this condition using information gathered from many different sources—federal and provincial ministries of agriculture, natural resources, and environment; universities; farm groups; and others. Effort has been made to present findings that are representative and interpretations that are reasoned and balanced. Opinions on the subject of water quality and quantity are almost as numerous and diverse as water users themselves, so we encourage the reader to use this report as a stepping stone to further thought and research, knowing that more work is needed to fully monitor conditions and understand the issues.

Throughout this report, the term *rural water* is used for the most part to mean freshwater used by and affected by primary agriculture.

Occasional reference is made to coastal waters, but a full discussion of the effects of agriculture on dykeland, estuarine, and marine water quality is beyond the scope of this report. Issues of water quality and quantity relating to the food processing industry are not discussed. Although many things may affect the quality and quantity of rural water, this report is limited to those aspects denoted by the chapter headings.

Each chapter is written to stand alone (each may be cited as an individual document for which the correct citation is given on page vi), but the reader will benefit most from reading the entire report. If this is not possible, the highlights at the beginning of each chapter capture the main points of interest.

We intend this report to be understood by people who are not scientists. However, we have not avoided technical words and concepts completely. These words are italicized at their first appearance and defined either in the text or the glossary at the end of the report, along with other helpful definitions.

2. Canada's Rural Water Resources

F.R.J. Martin, A. Bootsma, D.R. Coote, B.G. Fairley, L.J. Gregorich, J. Lebedin, P.H. Milburn, B.J. Stewart, and T.W. Van der Gulik

- Canada's climate is an important factor in determining the water resources and water conditions in the different parts of the country and in the different regions. Agriculture in Canada flourishes in every moisture zone. The driest regions require irrigation to maintain productive agriculture, but improved drainage is needed in the wettest regions to be able to cultivate fields.
- After direct precipitation, which supplies water for the growth of crops, surface water is the main source of water for agriculture and rural economies in all regions except Prince Edward Island, which depends entirely on groundwater. Alberta and Central Canada use groundwater to a lesser extent, but the total quantity used in Central Canada is the greatest because total water use is so high. Groundwater in prairie aquifers is often of naturally poor quality and may be unsuitable for drinking or irrigation.
- Surface water is often diverted from one river sub-basin to another. Where water crosses provincial and international boundaries, the flows must meet the terms of binding agreements.

Introduction

Water is essential for life, so the availability of water has a major influence on the kinds of ecosystems that are found throughout the world. Agriculture and the rural environment are part of the ecosystems in which they occur, and water forms one of the most important links between all living components of an ecosystem.

Water supplies for agriculture and other rural users can only be fully understood in the context of the *hydrologic cycle*. It is through this cycle that the earth's water resources are constantly replenished.

The hydrologic cycle

The hydrologic cycle, also called the *water cycle*, is really a giant distillation system that involves the earth and its oceans and atmosphere (Fig. 2-1). The energy driving the system comes from the sun. The total amount of water in the system stays roughly constant, but the water is always moving and changing from one state (i.e., liquid, gas or vapour, or solid) to another.

Simply put, the water cycle begins when water evaporates from the land and the oceans into the atmosphere. Warm, moisture-laden air rises and cools, condensing around dust particles to form clouds, which are moved around by prevailing winds. When the clouds become saturated and the water is too heavy to be suspended in air, water falls from the sky as *precipitation* (e.g., rain, snow, sleet, and hail).

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Highlights

- Water flows through a continuous cycle from the atmosphere to the earth's surface and back to the atmosphere again. Most users take advantage of its availability as freshwater in the soil, and in streams, lakes, and groundwater.
- Canada's climate is so variable that there are rainforests on the west coast and semi-arid conditions in the driest parts of the Prairies and British Columbia. Agriculture in Canada flourishes in every moisture zone. The driest regions require irrigation to maintain productive agriculture, but improved drainage is needed in the wettest regions to be able to cultivate fields.
- After direct precipitation, which supplies water for the growth of crops, surface water is the main source of water for agriculture and rural economies in all regions except Prince Edward Island, which depends entirely on groundwater. Alberta and Central Canada use groundwater to a lesser extent, but the total quantity used in Central Canada is the greatest because total water use is so high. Groundwater in prairie aquifers is often of naturally poor quality and may be unsuitable for drinking or irrigation.
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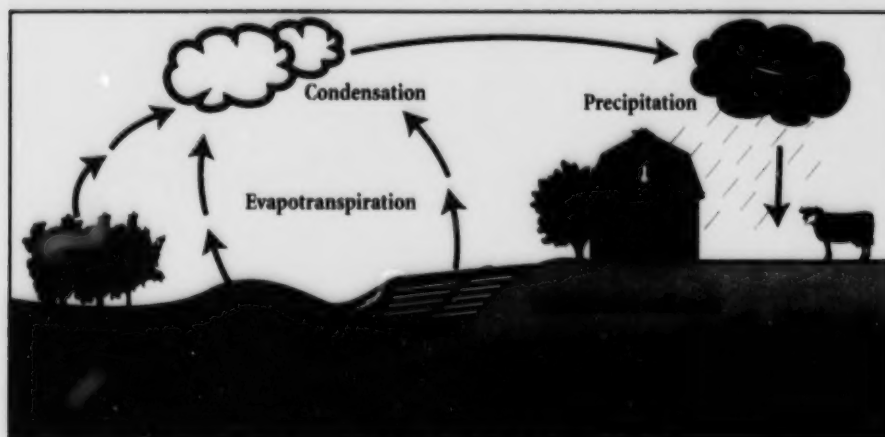
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Figure 2-1
Hydrologic cycle



This water may then take one of several pathways. It may

- evaporate again into the atmosphere from the earth's surface
- be taken up by plants
- be stored in solid form as snowpacks or glaciers
- be stored in liquid form in swamps and lakes
- flow over the land surface into streams
- infiltrate into the ground.

Most of the water intercepted or taken up by plants, and some of the stored water, evaporates back into the atmosphere.

The water that penetrates into the ground may

- be stored in unsaturated soil
- percolate down through the soil until it reaches the *water table*, where it becomes *groundwater*.

Water stored in soil eventually returns to the atmosphere by evaporation or is taken up by plants and then returned to the atmosphere by *transpiration* from plant leaves. Together these processes make up *evapotranspiration*.

Groundwater may be just below the surface or may move to great depths underground in aquifers. Eventually much deep groundwater flows to shallower levels in valleys and downslope of recharge areas. There it can be used by plants and transpired back into the atmosphere. As well, it can discharge into springs, lakes, or streams, from which it may evaporate or else join the stream flow into larger bodies of water. Some water makes it to the ocean, where evaporation continues to drive the water cycle.

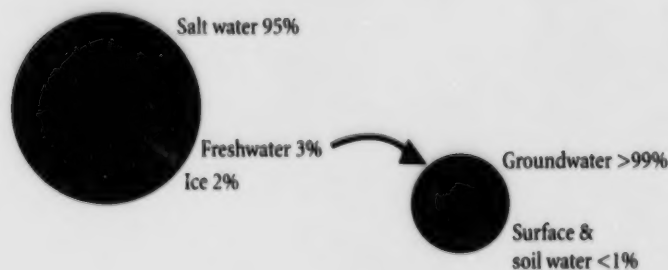
Canada's rural water comes from precipitation (rainfall and melted snow) and, in a few cases, from the melting of mountain glaciers. Water for rural use is generally taken from surface supplies, such as streams and lakes, or by pumping groundwater from wells.

Canada's water resources

Globally, the oceans contain more than 95% of the earth's water, but this water is too salty to use in its normal state, except as habitat for marine organisms and a medium for human transportation. The remaining water (less than 5%) is fresh. One-third of this water is stored in ice caps and glaciers. Most of the rest is groundwater, with only a very small portion (about 0.2%) found in the soil and in surface waters, such as lakes and rivers (Fig. 2-2).

Canada probably has more lake area than any other country in the world. It shares with the United States the Great Lakes, which hold about 18% of all the world's surface freshwater. On

Figure 2-2
The earth's water resources



average, about 9% of the world's renewable freshwater supply flows in Canadian rivers. Since Canada occupies 7% of the earth's land area, its freshwater supplies are not out of proportion. But with less than 1% of the world's population, Canada is generously supplied with freshwater, though this supply is not evenly distributed throughout the country.

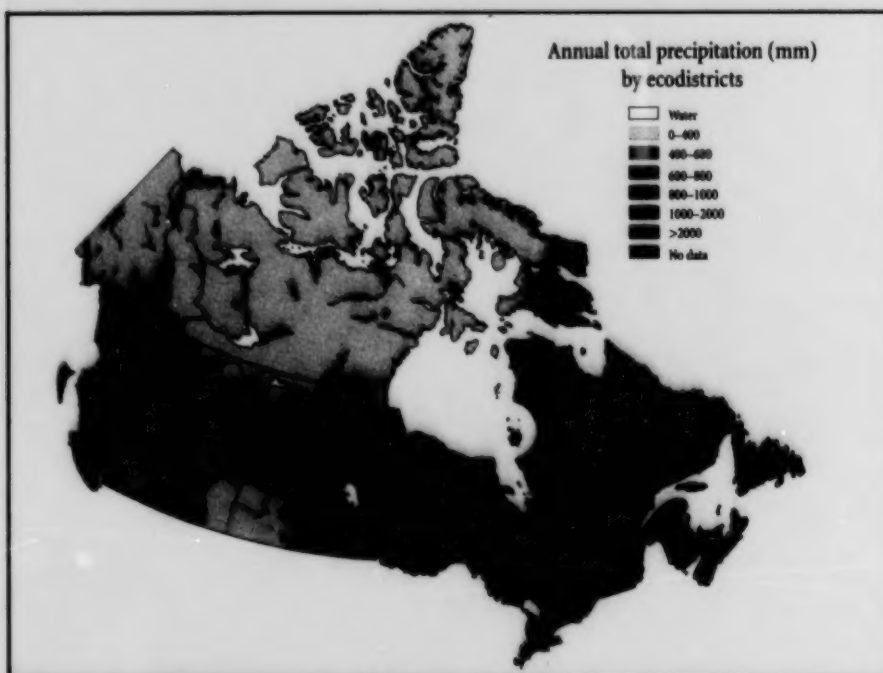
Because of Canada's different climatic zones, some parts of British Columbia and the Prairies are so dry that they compare with northern Mexico and much of Australia. Other parts of Canada, such as southern Ontario, suffer water shortages only during extended dry periods. In these regions the climate is more like the mid-western United States and central Europe. Canada's east and west coasts receive a good deal of rain, comparing more to Scandinavia. Thus, water management in Canada must be adapted to a wide range of conditions and can benefit from experience obtained in other parts of the world.

Water gains and losses

The wetness of the coastal regions and the dryness of the Prairies are evident in the overview of total precipitation (rainfall plus snow) across Canada (Fig. 2-3). Total precipitation is best interpreted in relation to *potential evapotranspiration*, which is the potential for water to evaporate from soils and transpire from vegetation (Fig. 2-4).

The difference between total precipitation during the growing season, together with the amount of water that can be held in the root zone of the soil, and potential evapotranspiration is called the *soil moisture deficit*. This value tells us by how much the land is actually short of water compared with the amount of water that plants could use if it were available. Most of western Canada where agriculture is found, as well as southern Ontario, suffers soil moisture deficits in an average year (Fig. 2-5). Most of Quebec and Atlantic Canada has enough soil moisture to meet the needs of vegetation in an average year.

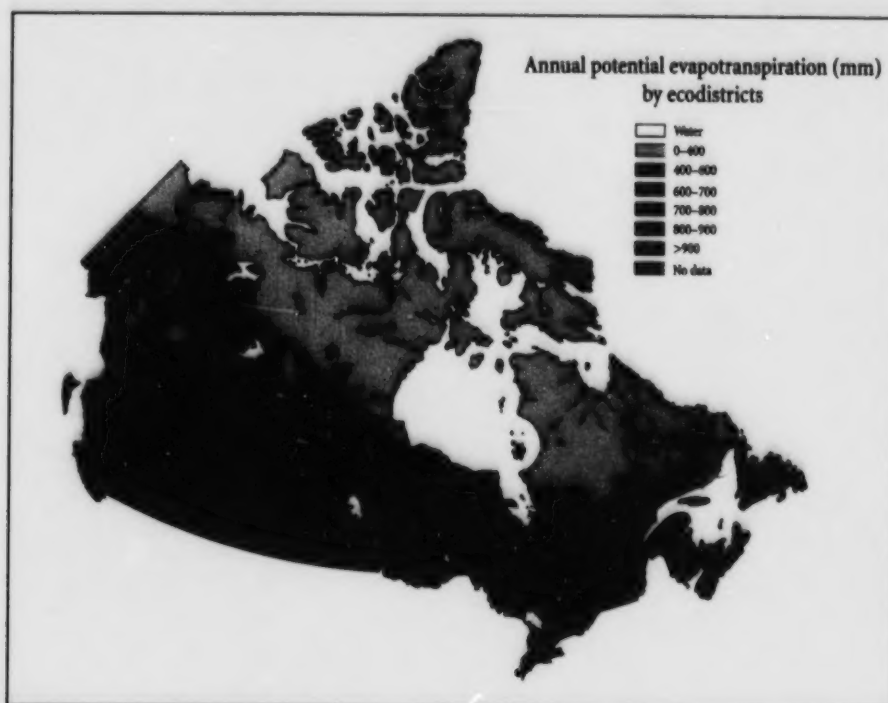
Precipitation that falls in the nongrowing season first replenishes the soil, then recharges groundwater or becomes *surface runoff*. Some



Source: Agriculture and Agri-Food Canada, 1998

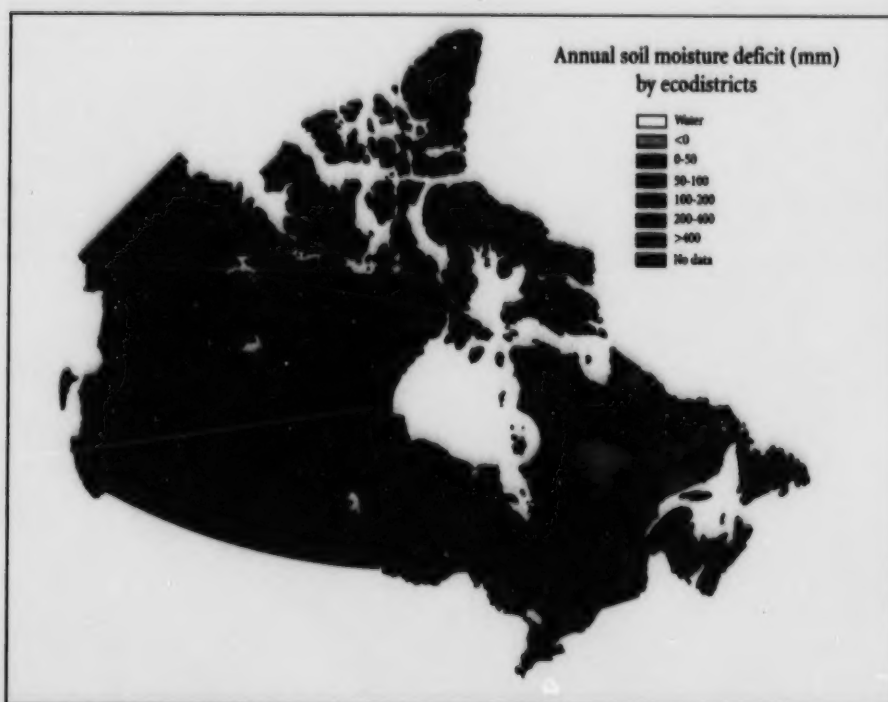
Figure 2-3
Total precipitation

Figure 2-4
Potential evapotranspiration



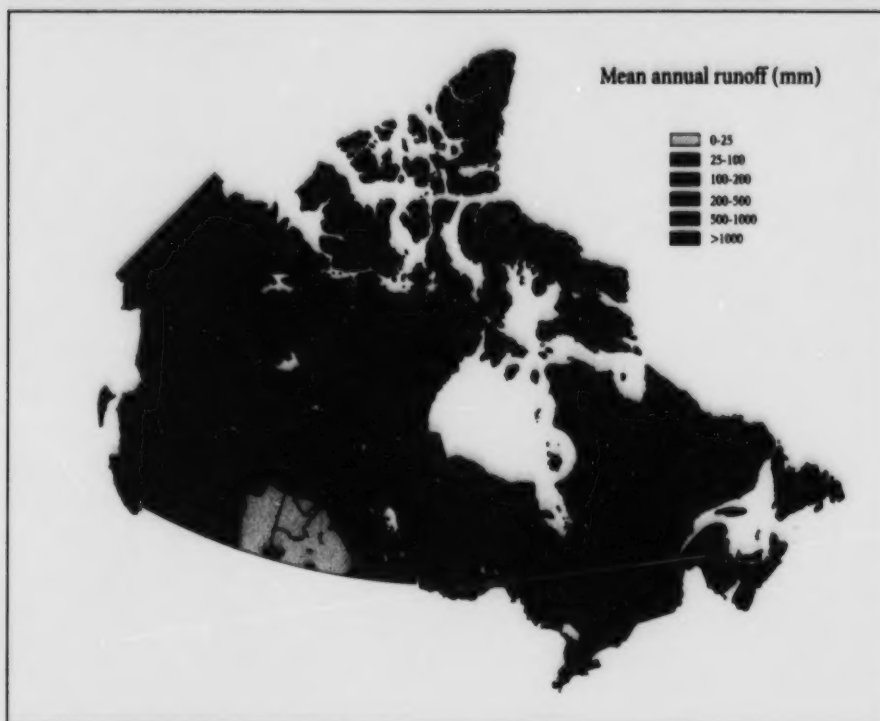
Source: Agriculture and Agri-Food Canada, 1996

Figure 2-5
Soil moisture deficit



Source: Agriculture and Agri-Food Canada, 1996

Figure 2-6
Annual runoff



Source: Fisheries and Environment Canada, 1978

heavy rainfalls in the growing season also contribute to surface runoff. Surface runoff feeds streams and rivers and increases flows above their baseline levels, which are usually maintained by groundwater discharge. Total stream flow combines surface runoff and groundwater discharge (*baseflow*) and is just called *runoff*. Average annual runoff follows a pattern similar to that of total precipitation but is only 10 to 50% of precipitation in the agricultural parts of central and western Canada (Fig. 2-6).

Canada's available water is not evenly distributed across the country nor among those who wish to use it. Provincial governments generally control who can have access to water and who can use it (see Box, p. 10).

Surface water

British Columbia

British Columbia is the site of the highest, and some of the lowest, precipitation in Canada. In the southern and most populated part of the province, the rivers rise in the mountains and

then flow southwards. The biggest river, the Fraser River, flows into the Pacific Ocean through Vancouver. The other major rivers are the Columbia River, which flows into the United States, and the Peace River, which flows to the Arctic.

Abundant precipitation occurs in the Pacific Maritime ecozone, which includes the coastal rainforests. However, in the dry interior, where annual precipitation is less than 400 millimetres, water is scarce for irrigation and domestic use. Most precipitation falls in the winter months, and little during the summer. Water is often stored in reservoirs created by small dams. Most of these reservoirs are licensed for irrigation use. They are also used for recreation and as habitat for fish and wildlife.

Surface sources supply 82% of British Columbia's municipal, domestic, and rural water. Farmers pump 70% of their irrigation water with their own systems from reservoirs, streams, and groundwater. Irrigation districts, generally located in the drier regions of the province where water costs are higher, supply water to 20% of the



Lake in British Columbia

Who owns the water?

The question of who owns the water in Canada does not have a simple answer. At the time of European settlement, it was thought that no one owned the water. It may have been recognized, even at that time, that Aboriginal people had some entitlement to use water, but the prevailing doctrines of English and French law emphatically suggested that running water could not be owned by any individual. Water was owned by a person only when it was captured, and then only in the actual quantity captured. English common law recognized that only riparian owners (the limited class of people whose land adjoined a watercourse) had rights to use water for domestic purposes and a restricted right to use water for other purposes, provided these uses did not perceptibly alter the quality or quantity of its natural flow.

This fundamental legal assumption started to change in western Canada when settlers were faced with the realities of farming in an arid region. In 1894–1895 the federal government perceived a need to provide secure water rights to settlers to encourage irrigated agriculture. In 1895 it enacted the *North-West Irrigation Act*, declaring that “the property in and the right to the use” of all water was vested in the Crown. Having thus brought water firmly under its control, the federal government granted rights to others, in the form of licences, to divert and use water in quantities and at locations that the common law of riparian rights did not allow.

In 1930, as part of the general transfer of natural resources, the provinces of Alberta, Saskatchewan, and Manitoba assumed ownership of water inside their boundaries. British Columbia had placed itself in a similar position in 1925 by declaring that it too owned and had the right to use all water. In the Northwest and Yukon territories and Nunavut, the property in and right to the use and flow of all water now vests in the Crown.

Thus, today there is a basic division between western and northern Canada, where the Crown has declared that it owns the water, and most of central and eastern Canada, including Quebec, where, under the same European principles applied at the time of settlement, no one owns water. In Nova Scotia, however, by a provision broadly similar to that found in the West, all watercourses are vested in the province along with the right to use and divert the water they contain.

This division between regions on the question of who owns the water emphasizes that this question is not of fundamental importance. No matter who owns the water, provincial governments can control water so as to regulate all significant issues of quality and quantity. Thus, for example, in western and northern Canada, the Crown allocates the right to divert and consume water by granting licences to those who apply for them. In central and eastern Canada, where water shortages are less common, the rights to divert and use water still belong to riparian owners. But there is no doubt that the governments of provinces in these regions control water within their boundaries enough that they could enact licensing or permit systems similar to those in western and northern Canada. For example, Ontario has added to its basic riparian rights a permit system allowing the provincial government to monitor and control all major consumptive uses of water. Nova Scotia can grant authorizations to use water, which are somewhat similar to the licences issued in the West and North, in a system that retains some vestiges of riparian rights. The ability to control all waters within their boundaries has also allowed the provinces to make provisions controlling water pollution, an issue of water quality.

Thus, the question of water ownership is no longer central. Today the main difficulty arises from the extent to which authority and control over water are divided between federal and provincial governments. In simple terms, most aspects of water management are within provincial authority. The federal government has the right to regulate water as it affects fisheries and navigation, based on provisions to that effect in the *Constitution Act*. A cloud of doubt surrounds jurisdiction over interprovincial bodies of water, for which the division of powers is quite uncertain. In practice, the provinces can effectively regulate both quality and quantity of these waters day to day, but the federal government could intervene in this management at any time by legislation.

D.R. Percy, University of Alberta

irrigated land base. Irrigation or municipal districts in the Okanagan and Kootenay regions supply water to farms through pressurized lines for both irrigation and domestic use.

Ponds and *dugouts* are rarely used for irrigation unless they are replenished during the summer by springs, seepage, or rainfall runoff. However, they are an important source of farmstead water in the Peace River area and on Vancouver Island. These small storages are usually limited to livestock watering, domestic use, and garden irrigation.

Prairie Provinces

The Prairies are the driest region of Canada. The agricultural land receives an average of 300 to 500 millimetres of precipitation each year, but evaporation would remove as much as 600 to 1100 millimetres if the water were available. More water is lost by evaporation than by any other process or use in this region. This loss has a great impact on surface water supplies.

Most of the major river systems in the Prairies originate in the Rocky Mountains. The mountain-fed systems are generally reliable, and their runoff varies little from year to year. Their streamflow is supplied by the extended melt of the mountain snowpack, and runoff is maintained through the summer and fall by glacial melting. These rivers are supplemented by a few low-yielding rivers draining prairie land, which are subject to extreme fluctuations in flow (from none to ten times the average). Prairie streams often exist for only a few days or weeks during the spring snowmelt, and perhaps briefly after heavy rainstorms.

Glaciers left hundreds of thousands of small lakes and sloughs dotting the flat plains and rolling terrain of this region. Some lake basins in southern Alberta and Saskatchewan have internal drainage with no surface outflow, even in wet years. Because there is no outflow, surface runoff is balanced by evaporation, so these water bodies expand in wet years and shrink or disappear entirely in dry years.

Dependable surface water supplies come mainly from large natural and constructed water bodies. Dugouts are also a common means of storing local runoff. They are usually designed to provide sufficient water to last 2 years, after accounting for



Prairie dugout

evaporation losses. If there are several consecutive dry years, they cannot maintain the supply. Of the 35 largest reservoirs found in this region, 21 supply water for irrigation and other uses. Because of the flat terrain and shallow river valleys, reservoirs often have a large surface-to-volume ratio and are subject to large evaporation losses.

Central Canada

Ontario and Quebec are generally well supplied with water provided by about 1000 millimetres of precipitation each year. Although surface water from the most populated parts of the region flows eastward through the Ottawa-St. Lawrence system to the Atlantic Ocean, almost 60% of total runoff flows northward into Hudson Bay. The relatively high potential evapotranspiration in the warmest parts of southern Ontario often leaves soils without adequate moisture during the growing season. Quebec, on the other hand, has slightly lower potential evapotranspiration and more precipitation, so is more like Atlantic Canada with respect to soil moisture and surface runoff.

In contrast to the Prairies, there are few dugouts in this region, and the reservoirs are for power generation and municipal supply rather than for irrigation. No organized irrigation districts exist, and irrigation is carried out almost entirely under private licence.

Historically, drainage to remove excess surface water has dominated the management of water in



Agricultural drain in Ontario

this region. Extensive drainage systems were developed by early settlers to make agriculture possible. Such systems were especially important in the productive clay soils of southwestern Ontario and the Ottawa and St. Lawrence valleys. They have evolved into a network of municipal drains that now serve the agricultural portion of the region.

The region's water managers are preoccupied with supplying water for the large urban and rural populations, and the extensive industrial activity. Water is extracted for municipal water supplies directly from the Great Lakes in Ontario, as well as from rivers throughout the region. Central Canada relies more on surface water than any other region, with almost 94% of the combined municipal, industrial, rural, and agricultural use being provided from this source. When thermal power generation is included, this figure rises to almost 98%.

Atlantic Provinces

The Atlantic region has one of the highest levels of runoff in the country—almost 83% of its precipitation runs off in rivers and streams. Factors that contribute to this high runoff include

- high annual precipitation: on average, most of the region receives more than 1000 millimetres of precipitation each year, matched or exceeded only in parts of Quebec and in the mountains of British Columbia
- low rates of evaporation and transpiration: most of the region has potential evapotranspiration of less than half the precipitation

- many steep slopes, which hasten runoff to streams.

Despite the large volume of runoff, only 50% of the people obtain their water from surface sources (almost 0% in Prince Edward Island)—a smaller share of the population than in any other region in Canada. Because of the moist climate, little irrigation is carried out in the Atlantic provinces. Reservoirs are used almost exclusively for hydroelectric power generation and municipal water supply. Most of the nearly 300 000 water bodies in the region (270 000 in Newfoundland and Labrador) are quite small; only about 30 exceed 100 square kilometres.

Groundwater

British Columbia

Many of the valleys that shape British Columbia's landscape are underlain by sand and gravel aquifers that are valuable reservoirs of groundwater. Limestone bedrock also supplies groundwater on Vancouver Island and in part of the southern interior. About 12% of all the water used in the province comes from groundwater.

Only 40% of British Columbia's rural water supplies are provided by wells, a lower share than anywhere else in Canada except for the Northwest Territories. Groundwater is also the source of water for only 2% of irrigated land in British Columbia. However, it is the sole source for irrigation in portions of the Fraser Valley, south Okanagan Valley, and parts of the Kootenays.

This wide variability in the use of groundwater reflects the extremes of surface water supplies—from excessive runoff in coastal and mountain areas with the highest precipitation in Canada to central interior regions that are almost desert-like, with very low precipitation and runoff. In these dry areas, reliance on groundwater is essential.

Prairie Provinces

Groundwater is very important in the Prairies, because surface water is often scarce outside of organized irrigation districts. The region has many glacial deposits that contain valuable aquifers. As well, the glacial materials are underlain by extensive shale, sandstone, and limestone bedrock formations, many of which

contain extractable groundwater. Unfortunately, the water in many of these bedrock aquifers is of poor quality, containing a high concentration of salts, such as unpleasant-tasting sodium sulfates, as well as iron and manganese. Some of this water is unsuitable for humans or livestock to drink.

Manitoba extracts about 20% of all its water from aquifers, the highest share of any province except Prince Edward Island. Manitoba has especially important aquifers in the limestone bedrock underlying the Interlake region and Red River Valley, as well as in extensive glacial and deltaic sand deposits. Saskatchewan supplies 9% of its water needs from groundwater, and Alberta, only 4%, because of its proximity to the high-quality surface water flowing from the mountains.

About 90% of rural residences in the Prairies get their water from wells. A similar proportion of farms, spread fairly evenly across the region, use well water to water livestock. Irrigation, on the other hand, is highly variable, with 48% of its supply coming from groundwater in Manitoba and less than 1% from this source in Alberta. About 1% of irrigation is supplied by groundwater in Saskatchewan. These figures reflect the greater availability of surface water in Alberta, which is diverted into distribution systems in irrigation districts. A portion of this runoff is available to irrigators in Saskatchewan. In Manitoba, irrigation has developed mainly as privately supplied systems on extensive aquifers, such as the Assiniboine Delta Aquifer, which is capable of sustained pumping.

Central Canada

Much of the eastern Great Lakes Basin and southern Quebec (i.e., the part of the region east of Toronto that is not Canadian Shield) is underlain by limestone bedrock aquifers. In contrast to the Prairies, natural groundwater quality in Central Canada is generally good, with low levels of dissolved minerals.

Sand and gravel aquifers are found throughout the region as a result of glaciation, providing groundwater for many municipalities, rural residences, and farms. They are especially important in the heavily populated parts of southern Ontario east and west of Toronto, and throughout the St. Lawrence Valley in Quebec. An exception occurs in the southwestern Ontario clay

plain, where many rural wells are only poorly supplied with groundwater from shale bedrock.

Although the share of water used in Central Canada that comes from groundwater is among the lowest in the country (about 2.5%), the total amount is great. Central Canada accounts for more than 40% of all groundwater used in Canada.

Atlantic Provinces

Prince Edward Island is unique in Canada for its great dependence on groundwater—almost 100% of water used rurally and almost 90% of total water used comes from sandstone bedrock aquifers. Coarse sand and gravel deposits of glacial origin produce most groundwater in the rest of the region, although sandstone aquifers are also found extensively in eastern New Brunswick, Nova Scotia, and Newfoundland. Most wells usually meet the needs of single domestic dwellings and farms.

Groundwater quality is relatively good in Atlantic Canada, though most water from bedrock aquifers tends to be *hard*. In some coastal areas aquifers are susceptible to *sea water intrusion*. The town of Shippegan in northeastern New Brunswick and the town of Pictou on Nova Scotia's north shore have had to abandon wells because of this problem. As well, arsenic is sometimes present in wells in Hants and Colchester counties of Nova Scotia.

Diverted water

The highly variable annual runoff in the Prairies has made it necessary to develop surface water projects to store water, divert water, or both, to ensure water supplies, particularly during years of low runoff. Some of these projects are also designed to reduce the impact of damage caused by high flows in years of high runoff.

Diversion projects are either *intrabasin* (within the same river basin) or *interbasin* (into another river basin). In the Prairies, diversions exist between the sub-basins of the same major drainage basin in all three major drainage systems—the Saskatchewan–Nelson, the Peace–Athabasca, and the Missouri.



Domestic well

Major diversion projects in Alberta (e.g., the Bow River Diversion Project) are used mainly to supply water to the 13 irrigation districts in the southern part of the province. In Saskatchewan, major diversion projects (e.g., South Saskatchewan River Project–Lake Diefenbaker and Qu'Appelle Dam) are used mainly to supply water, including that used for irrigation, although they may also provide for flood control and recreation. In Manitoba, the major diversion projects (e.g., Portage Diversion Project, Winnipeg Floodway, and Carmen Floodway) are operated mainly for flood control.

There are also thousands of minor diversion projects throughout the Prairies, mainly designed to supply water. These projects meet the needs of irrigation projects, communities, and individuals. They normally divert water from a nearby storage project through open canals, pipelines, or both. They often experience water supply shortages, because runoff is so variable in the prairie region. Extended periods of *drought* can jeopardize even the most secure surface water sources.

Transboundary waters

Interprovincial

Outside the Prairies, few rivers cross provincial boundaries. Because water is largely a provincial responsibility, agreements exist between the provinces to manage specific water concerns. For example, the 1969 agreement among the three Prairie provinces ensures that

- one-half of the natural, eastward flow of waters rising in, or flowing through, Alberta is reserved for Saskatchewan
- one-half of the eastward flow rising in, or flowing through, Saskatchewan is reserved for Manitoba.

Other interprovincial agreements exist where they are needed. For example, the Ottawa River forms the provincial border between Ontario and Quebec for much of its length. It is used for hydroelectric power generation, water supply, and waste disposal by communities on both sides. A 1943 agreement between the provinces allows for the shared management of the river for generating hydroelectric power. Water supply and waste disposal take place on both sides of the border, which often follows the centre line of the river, and so are not covered by agreements.

International

The most important agreement related to water use and diversion that exists between Canada and the United States is the Boundary Waters Treaty, 1909. Under this treaty, 30 international water boards have been established with equal representation from each country to manage international rivers such as the Columbia, St. Mary–Milk, Red, Niagara, and Saint John rivers, and water bodies such as Lake of the Woods and the Great Lakes.

One international issue that occasionally arises is that of diverting water from the Great Lakes into the Mississippi River, originally to maintain navigation but now also to enhance water supply and effluent disposal. Pressure is sometimes exerted to increase the rate of diversion, but Canada and the American states that rely on the Great Lakes have successfully resisted any increase.

Conclusion

Canada is blessed with a good supply of freshwater for agriculture, home owners, industry, and wildlife. But because this supply is not evenly distributed across the country, crop production often depends on irrigation in the drier regions (see Chapter 3) and soil drainage in the more humid zones (see Chapter 10).

Groundwater is well distributed across the country and is relied upon to some extent in all regions. It is especially important for farmers and other rural residents, for whom a well is often the only practical source of water. However, in most regions surface water is the principal source for society as a whole, with surface water use outweighing groundwater use in Canada by 25:1.

Although the long-term effects of global warming on the continued availability of our freshwater supplies are still uncertain (see Chapter 11), it is likely that we can continue to enjoy this abundance for many years to come. However, if this resource is abused, through over-exploitation or pollution, we will be faced with an inadequate water supply to meet our needs.

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3. Water Use

E. Kienholz, F. Croteau, G.L. Fairchild, G.K. Guzzwell, D.I. Massé, and T.W. Van der Gulik

- In agriculture, most water is consumed, being used mainly to grow crops and water livestock, clean farm buildings and equipment, and meet domestic needs.
- The main competitors with agriculture for water are thermal power generation, manufacturing, and municipal uses. Fisheries, wildlife habitat, and human recreation also compete for water resources.
- Generally the provinces have jurisdiction over their waters, but federal legislation governs some aspects of water development and use. Water rights legislation has been developed to regulate the withdrawal of surface water and groundwater for beneficial uses.

Introduction

Water is used in a variety of ways (Fig. 3-1), but all uses fall into two groups. *Instream uses* leave water in place. They include fisheries, wildlife habitat, hydroelectric power generation, and recreation. *Withdrawal uses* remove water from its natural setting. In some cases, water is returned to the source after it is used, but in others it is *consumed* and is not available to be returned. These uses include irrigation, domestic and municipal uses, thermal power generation, and manufacturing.

On a national level, agriculture withdraws a relatively small amount of water (9%) compared with thermal power generation (63%) and manufacturing (16%) (Fig. 3-2). However, agriculture consumes a large portion of what it uses, returning less than 30% to its source, where it can be used again. About 75% of all agricultural withdrawals in Canada occur in the semi-arid prairie region.

The demand for water is growing in all sectors, increasing the potential for competition and conflict among water users. Irrigation (see Box, p. 16), the largest agricultural consumer of water, is often at the centre of such competition.



Figure 3-1
Rural uses of water

3. Water Use

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Highlights

- Water can be used in two ways. Instream uses leave water in place. Withdrawal uses remove water, sometimes returning it to the source, but often consuming it so that it is not returned for other uses.
- In agriculture, most water is consumed, being used mainly to grow crops and water livestock, clean farm buildings and equipment, and meet domestic needs.
- The main competitors with agriculture for water are thermal power generation, manufacturing, and municipal uses. Fisheries, wildlife habitat, and human recreation also compete for water resources.
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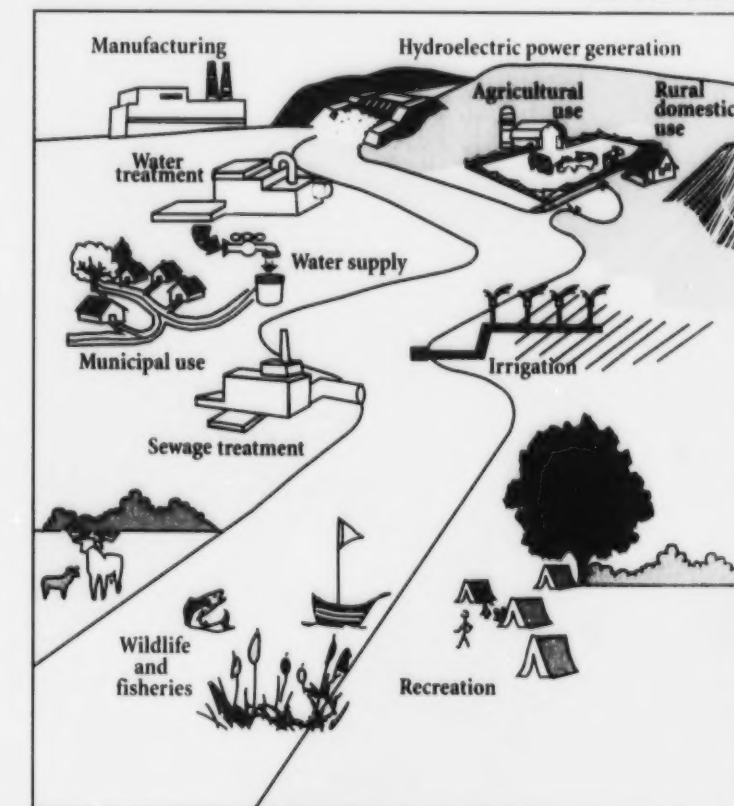
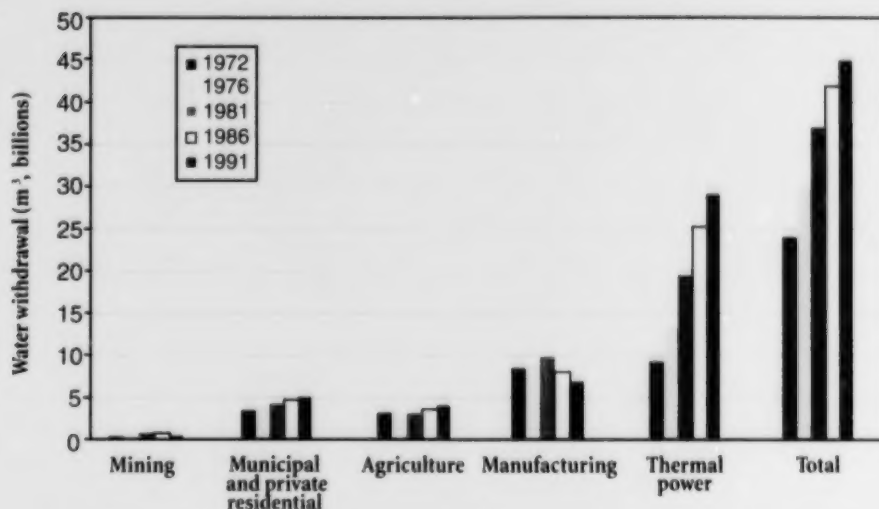




Figure 3-2
Total water withdrawals in
Canada, 1972–1991



Note: For municipal and private residential uses, private residential uses are estimates only and water supplied to industries from municipal supplies is excluded.

Source: Environment Canada, 1998

Economics of irrigation

In dry areas, cropping may be economically unsustainable without irrigation. During irrigation, water is applied to a crop to augment what it receives from soil storage and precipitation. It not only improves yields in most years but also can allow farmers to diversify and grow crops such as vegetables that might otherwise be too risky in dry areas. Under irrigation, potatoes and other vegetables often have the lowest costs of production in North America. For many vegetables and high-value crops, even in areas that are not dry, irrigation may make economic sense because the value of the increased yield may more than offset the investment cost.

Generally, investment in irrigation is more attractive in years when commodity prices are above average, and in areas where yields are below average because of insufficient rainfall or soils that do not hold water well. If commodity prices rise, the payoff from investment in irrigation also increases.

H. Clark, Saskatchewan Irrigation Diversification Centre

This chapter focuses on the major withdrawal uses of water for agriculture—irrigation, livestock production, and on-farm domestic use. Reference is also made to other rural water uses, such as power generation and recreation. The necessity of water as fish and wildlife habitat and the relationships between agriculture and aquatic habitat are dealt with in Chapter 7. A discussion of relevant

provincial and federal legislation and regulations that apply to the use of water concludes this chapter.

Agricultural use of water

Crop production

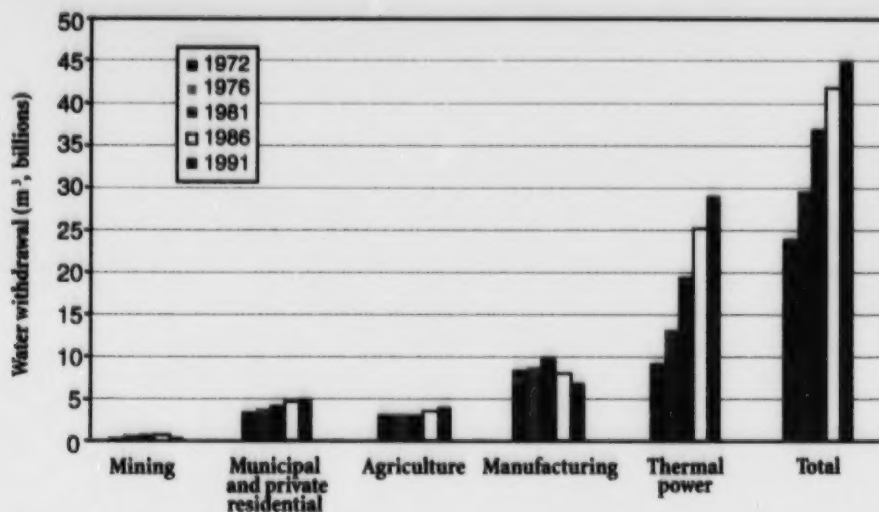
Water is used by plants to build tissue through the process of photosynthesis and to regulate temperature. Plants act like pumps, drawing water from the soil and moving it up to the leaves, where it evaporates into the atmosphere. Thus, the three main factors that determine how much soil water plants use are

- the type of plants
- the supply of water in the soil that is available to plants
- the amount of water that the atmosphere can draw from the plant and soil.

The process of moving soil water through the plant and into the atmosphere is transpiration. The maximum amount of water that plants could move under ideal conditions, together with unavoidable evaporation from the soil, is potential evapotranspiration, which depends on weather conditions. On warm, windy days, plants draw heavily on soil water, and on cool days, they draw less.

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Plants cannot use all the water in soil. Two physical limits determine the amount of soil water that is available to plants:

- *field capacity*, the upper limit
- *permanent wilting point*, the lower limit.

A soil is at field capacity after being thoroughly soaked and allowed to drain for a few days. If drainage is poor, crops can be damaged by excess water. As crops draw water from the soil, it becomes more difficult for them to use the water that is left. When they can no longer extract enough to meet their needs, they wilt. At the point at which plants can no longer recover from daytime wilting, called the permanent wilting point, soil water is no longer available to plants.

Between field capacity and the permanent wilting point, water held in the soil can be used by plants. This water is called *available water*, and how much is held by soil depends mainly on its *texture*. Medium- and heavy-textured soils, such as loams and clays, hold much more available water than coarser or sandy soils (Fig. 3-3). The efficiency of water use by plants is affected by

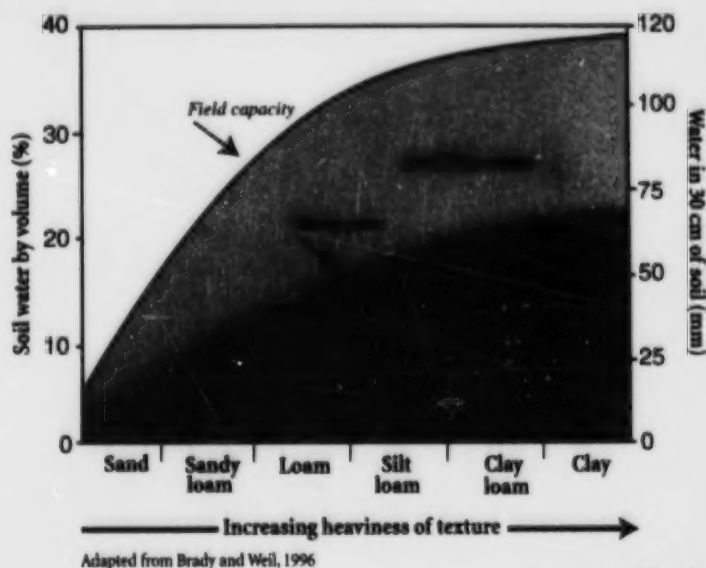
- other soil characteristics as well, including
- organic matter content
- structure
- nutrient content.

The right amount of moisture must be available at the right time in a plant's growth cycle for the successful production of agricultural crops. The average amount of water needed to produce top yields of various common crops is given in Table 3-1.

Irrigation

Dry regions in the interior of British Columbia and the southern Prairies have severe soil moisture deficits at some time during most summers and can suffer from long-term drought conditions. These areas hold most of the 1 million hectares of irrigated cropland in Canada (Fig. 3-4), with Alberta alone accounting for 60% (see Case Study). The relatively moister conditions found in central and eastern Canada reduce the need for supplemental water, but limited irrigation of high-value crops (e.g., fruits and vegetables) is practised. The benefits of irrigation include

- increased stability of production
- the potential for production of a diverse



Adapted from Brady and Weil, 1996

Figure 3-3
Relationship between soil
texture and soil water

Table 3-1
Water needs of various crops during the
growing season

Crop	Average water use (mm)	Growing season (days)
Alfalfa	635	155
Grass	610	150
Sugar beets	559	155
Potatoes	508	140
Spring wheat	457	100
Oats	406	95
Barley	406	90
Flax	381	100
Field corn	381	120
Tomatoes	356	105
Canning peas	330	80

Source: University of Saskatchewan, 1984

Case study Irrigation in Alberta

Alberta accounts for about 60% of irrigated agricultural land in Canada—about 620 thousand hectares (1533 thousand acres) were irrigated in 1997. More than three-quarters of this area is located in the 13 irrigation districts in southern Alberta, where private irrigation projects are also concentrated.

The Oldman and Bow river systems, whose flows come mainly from snowmelt in the Rocky Mountains, are the water source for all the irrigation districts. To capture and store spring runoff for irrigation use later in the summer, 48 reservoirs with a combined usable storage of 2826 cubic decametres (2289 thousand acre feet) have been constructed on these river systems. These reservoirs also supply water for municipal and industrial use, livestock watering, on-farm domestic use, and recreation.

In 1997, the total volume of water allocated to irrigation licensees in the 13 irrigation districts was 3438 cubic decametres (2785 thousand acre feet). However, the actual volume of water diverted was 68% of the licensed volume (the amount of water used varies considerably from year to year with fluctuations in precipitation and temperatures). In the decade preceding 1997, the volume of diverted water ranged from a high of 2879 cubic decametres (2332 thousand acre feet; 84% of allocation) in 1988, an extremely hot year, to a low of 1386 cubic decametres (1123 thousand acre feet; 40% of allocation) in 1993.

The breakdown of crops grown in the irrigation districts in 1997 was 40% cereals, 40% forages, 9% oilseeds, 11% specialty crops, and 0.5% other crops. The Taber Irrigation District showed the highest diversification into high-value specialty crops, with 29% of its irrigated area devoted to crops such as sugar beets, potatoes, and corn. Processing plants in or near Taber and Lethbridge support greater production of specialty crops, as does the more-favourable climate. Specialty crops were also important in the Saint Mary River and Bow River irrigation districts.

According to 1994 data, on-farm irrigation types were predominantly side-roll-wheel-move sprinklers or stationary centre pivots, which accounted for 33% and 30% of the total area irrigated, respectively. The less-efficient gravity systems accounted for 20% of the irrigated area, and trickle-drip systems, still in the early stages of development, for only 0.1%. Considerable progress has been made in moving to more-efficient application systems since the early 1970s, when sprinkler systems were used on only 20% of irrigated land.

Continuing efforts to modernize irrigation works in the province since the 1970s have involved rehabilitating irrigation headworks, main canals, and distribution systems. These improvements have included canal relocations, lining improvements, erosion protection, drains, and pipeline construction. Updating water allocations for each district in the early 1990s, developing new legislation, and undertaking research and extension have all been directed at improving water use efficiency and management.

The development of irrigation in Alberta was based on 1895 legislation that gave ownership and regulation of all surface waters to the Crown. The *Alberta Irrigation Districts Act* of 1915, forerunner of the present *Irrigation Act* (1968), allowed for irrigation districts to be established. The South Saskatchewan Basin Water Allocation Regulations ensure that water shortages do not occur, by regulating the amount of land that can be irrigated. Under these regulations, Alberta Agriculture, Food and Rural Development estimates that the irrigated area could expand to 688 thousand hectares (1700 thousand acres). A new irrigation act was passed in the provincial legislature in 1999. The act confirms irrigation districts as independent corporations responsible for managing the water in the districts. It also allows them to become involved with activities that bring in extra revenue. For example, Irican, a business activity under the control of the Saint Mary River and Raymond irrigation districts, operates two small hydroelectricity developments situated on main canals.

E. Kienholz, Agriculture and Agri-Food Canada

- range of high-value crops
- intensification of production.

The peak design flow rate of an irrigation system varies according to climate, crops, and soil conditions. An estimate can be made from the peak evapotranspiration rate (Table 3-2). The amount of water withdrawn for irrigation varies annually and depends mainly on two factors:

- winter precipitation
- weather and soil moisture conditions during the growing season.

In areas such as southwest Saskatchewan, spring runoff determines the amount of water available for irrigation during the following summer. Temperature, the amount and timing of rainfall, wind, and evaporation all influence the need for supplemental water for optimum plant growth.

Water use for larger irrigation projects is often licensed by the province in which they are located, as a means of controlling total withdrawals from a water source and minimizing the potential for conflicts among users. The licence stipulates the maximum volume of water that can be withdrawn in a year. The licensed amount is often considerably greater than that withdrawn in an average year.

The expansion of irrigated area depends on both soil characteristics and a secure supply of water of suitable quality. Some provinces require irrigators to undertake a soil water compatibility study before approving irrigation plans.

To limit competition with other water users, irrigators, private industry, governments, and researchers have cooperated to introduce greater efficiencies in the way irrigation water is stored, conveyed, and applied in the field. For example:

- Irrigation headworks, main canals, and whole distribution systems have been renovated to minimize water loss.
- Irrigators are encouraged to switch from less-efficient gravity systems to more-efficient sprinkler systems or to highly efficient drip or trickle systems.
- Some irrigators are converting *saline* land back to *dryland*.
- Governments and industry are conducting research and demonstration projects to determine the applicability of new

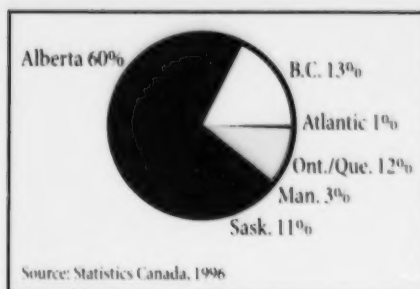


Figure 3-4
Distribution of irrigated
land in Canada

irrigation technologies (see Box below) and to identify the actual water requirements of irrigated crops.

- Water meters are being used at the district and farm levels to measure water use and charge for water based on consumption.

Water use efficiency is discussed further in Chapters 9 and 11.

Table 3-2
Irrigation system flow rate requirements

Evapotranspiration rate (mm/day)	Irrigation system flow rate (L/s per ha)
3	0.5
4	0.68
5	0.84
6	1.03
7	1.18

Source: Irrigation Industry Association of British Columbia, 1989

New irrigation technology

The Saskatchewan Irrigation Diversification Centre in Outlook, Sask., recently began research to evaluate a relatively new technology—Low Elevation Spray Application (LESA)—under prairie conditions. Centre pivot irrigation requires high energy inputs, limiting its sustainable use. In this study, a centre pivot equipped with standard nozzles was modified from a medium- to a low-pressure system by adding drop tubes and low-drift nozzles.

Both standard and low-drift nozzles were less efficient with increasing wind speed, but the low-drift nozzles were more efficient at all wind speeds. Compared with the medium-pressure system, on average the LESA technology

- was 8% more efficient
- used one-half the energy to deliver the same amount of water.

K.B. Stonehouse, University of Saskatchewan

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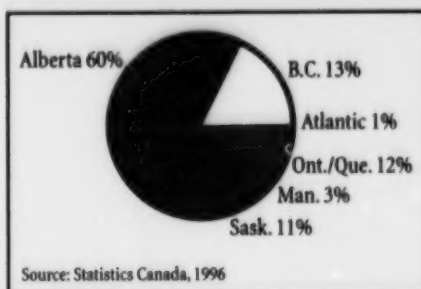


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Effluent irrigation, using treated municipal wastewater as the source of supply, is recognized as an environmentally acceptable and efficient method of disposing of treated municipal wastewater (see Box). Practised by towns and cities across Canada, notably in the Prairies, it provides a valuable source of irrigation water and nutrients for forages and other agricultural crops, especially in areas short of water.

Frost protection

Water can be used as a method to protect crops against frost by

- crop flooding, as is done with cranberries
- over-head sprinkling for bloom delay on horticultural crops
- over- and under-tree sprinkling during frost occurrences, as with tree fruit and grapes.

A flow rate of 6.5 to 10 litres per second per hectare is needed, depending on the severity of the frost.

Livestock production

Livestock production depends on ready access to water of suitable quality. The main use of water is for drinking, but it is also used to clean facilities, sanitize equipment, and dilute manure.

Water is important to animal growth and maintenance of body tissues, reproduction, and lactation. Animals lose body water in expired air, milk, urine, and feces, and by evaporation from the skin. Animals whose water intake is restricted, either because of limited supplies or poor quality, will likely eat and grow less and be less productive. In some cases, they may become sick and even die.

How much an animal drinks depends on

- the species
- physiological conditions, such as age and whether the animal is lactating
- environmental factors, such as temperature, humidity, activity level, and water content of the feed.

For example, a lactating dairy cow may drink 70 to 140 litres daily, whereas a dry cow requires only 35 to 60 litres daily. Table 3-3 shows average daily water requirements for different types of livestock.

Table 3-3
Daily water needs of farm animals

Animal type	Water (L/day)
Beef feeder	35
Beef cow	55
Dairy cow	160
Lactating sow	20
Feeder pig	10
Ewe	7
Chicken layer	0.25–0.30
Chicken broiler	0.15–0.20

Source: University of Saskatchewan, 1984

Figure 3-5 shows how water is used in a dairy operation. Opportunities exist to reduce the amount of water used, through

- scraping or sweeping floors before washing
- reusing equipment rinse water to wash floors
- using high-pressure nozzles for washing
- installing water-saving sinks
- using the first rinse water from milk lines to water calves.

Reducing the volume of water used has the added benefit of reducing the amount of wastewater that must be stored and handled.

Studies on the use of water in hog barns have shown that considerable water savings can be achieved by using bowls and hopper waterers instead of nipple waterers, the most common watering system in hog barns. Growing and finishing pigs may waste up to 60% of the water from a nipple drinker. This wastage adds greatly to the volume of wastewater and the cost of storing and disposing of effluent.

Rural domestic use

Farmers and other rural residents, unlike their urban cousins, are directly responsible for their own water supply. The source of water may include one, or a combination, of

- a shallow or deep groundwater well
- a lake, stream, river, or on-farm storage pond or dugout
- a cistern filled by rainwater or by hauling water from a distant source
- a regional water supply pipeline (see Box this page).

In emergencies, rural families may also resort to buying bottled water for drinking and cooking.

Different water sources may be used for different purposes, such as drinking, watering lawn and garden, and watering livestock. Some type of treatment is often needed to ensure that the water used for household purposes is of suitable quality. Developing a dependable supply of water often involves considerable initial costs, ranging from \$5000 to \$25 000. Rural residents must also pay for in-home treatment systems and ongoing operation and maintenance costs.

Canadians are next only to Americans in the average amount of water each person uses daily

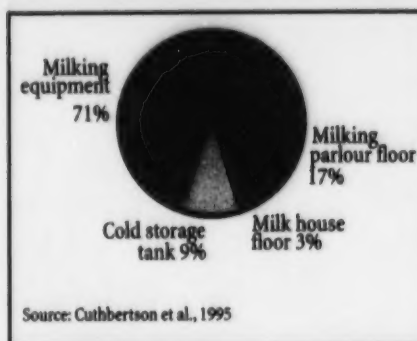


Figure 3-5
Water use in a milking parlour

Fighting the water

Development of many rural water pipelines during the 1940s and 1950s has provided a reliable and high-quality source of water to many people living on the prairies. Such pipelines were made possible by the advent of flexible, non-corrosive polyethylene pipes, which are low in cost and easily installed. The dependable supply of water offered by these pipelines has opened new opportunities for economic development and expansion and increased the quality of life in the rural sector. Although the pipelines are usually owned and operated by local municipalities, groups have been exclusively and cooperatively owned by producers and agri-food councils (Prairie Producers Association, Saskatchewan and provincial agencies within the last decade).

The benefits of a rural water pipeline are illustrated by the experience of one farm family with two adults and one teenage living in southern Saskatchewan. Prior to their connection with the pipeline in 1950, this family had always bought household water a kilometre from Weyburn, Sask. When water was good, water in the well and dugout water was of poor quality. On average, they hauled about three tank-loads, during the week in a half-ton delivery in the basement. Although water was less plentiful daily, study of water bills from the previous daily shows the pipeline was installed, the family notes that "not having to haul water every week is one of the best things to happen at the farm."

3. Pipelines, Agriculture and Agri-Food Councils



Effluent irrigation

Using treated municipal effluent as a source of water for irrigating agricultural crops, trees, or golf courses is a well-established practice in the Prairie provinces. About 65 projects irrigating a total of 5700 hectares now exist. These projects account for less than 5% of the total discharge of effluent on the Prairies, but 115 000 hectares could be irrigated if this practice was expanded. Such expansion could also reduce or eliminate undesirable discharges into natural waterways. Studies show that effluent irrigation is sustainable provided that projects are properly designed and managed to protect soil and water quality.

E. Kienholz, Agriculture and Agri-Food Canada

Both effluent users and the general public need to understand the environmental sustainability of these projects. Effluent irrigation to promote economic development should be considered only where long-term sustainability of the site is possible and appropriate monitoring measures are incorporated to measure changes in the ecosystem. Effluent irrigation for the purpose of disposal is generally considered the least environmentally damaging solution to a municipal disposal problem. Sustainability in these cases might be viewed as sustainability of the environment at large as opposed to sustainability of the disposal site. Predicting sustainability and establishing monitoring procedures are essential in allowing regulatory agencies to evaluate the potential of any site for effluent irrigation.

T.J. Hogg and L.C. Tollefson, Saskatchewan Irrigation Diversification Centre

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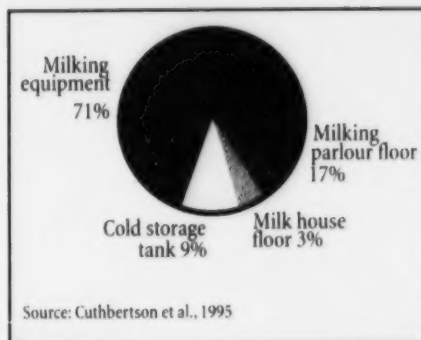


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Water use in a milking parlour

Piping in the water

Development of many rural water pipelines during the 1980s and 1990s has provided a reliable and high-quality supply of water to many people living on the Prairies. Such pipelines were made possible by the advent of durable, small-diameter polyethylene pipe, which is low in cost and easily installed. The dependable supply of water offered by these pipelines has opened new opportunities for economic development and expansion and improved the quality of life in the areas served. Although the pipelines are usually owned and operated by local associations, groups have been technically and financially assisted by Agriculture and Agri-Food Canada (Prairie Farm Rehabilitation Administration) and provincial agencies within the three Prairie provinces.

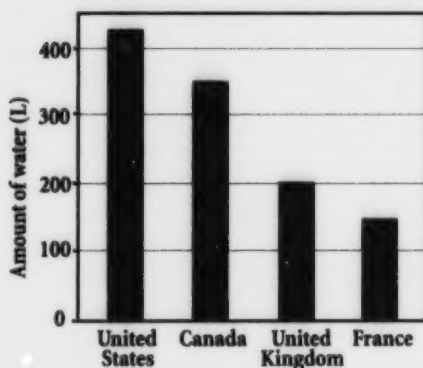
The benefits of a rural water pipeline are illustrated by the experience of one farm family, with two adults and one teenager, living in southeast Saskatchewan. Prior to their connection with the pipeline in 1996, this family had always hauled household water 8 kilometres from Weyburn, Sask. There were no good wells in the area and dugout water was of poor quality. On average, they hauled 4500 litres each week, storing the water in a 9100-litre cistern in the basement. Although water use has remained fairly steady at about 216 litres per person daily since the pipeline was installed, the family states that "not having to haul water every week is one of the best things to happen at the farm!"

E. Kienholz, Agriculture and Agri-Food Canada



Pipeline construction

Figure 3-6
Average daily household
water used per person



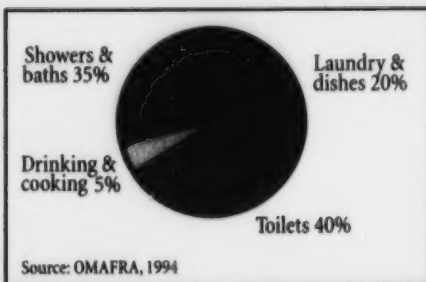
Source: OMAFRA, 1994

(Fig. 3-6). How domestic use in rural areas compares with this average is difficult to say, because there are no provincial requirements for licensing domestic on-farm water use, and water used by rural residents is rarely metered. An exception to this occurs in the Prairies for recently constructed regional water supply pipelines.

Meters on individual connections to pipelines in southeast Saskatchewan show that the average daily water use per person, assuming little water is used for outdoor purposes, ranges from 225 to 373 litres. The age of family members is a factor in water use, with the highest consumption occurring in households with babies and young children. In comparison, metered water use in southern Alberta for a family of five with a private water supply and treatment system was 155 litres per person daily, assuming little outdoor use.

These figures indicate that rural residents use slightly less water for domestic purposes than the average Canadian residing in a community with a population of more than 1000. Data on municipal water use compiled by Environment Canada show that in 1994 the average daily use per person ranged from 258 to 445 litres. The lower figure is

Figure 3-7
Average water use in
Canadian homes



Source: OMAFRA, 1994

for households that paid for water based on volume used, and the higher rate is for households that paid a flat rate, regardless of the volume used.

To some extent, domestic water use by rural residents is influenced by the same factors that affect urban residents. Adults generally use less water than teenagers and young children. The growing use of dishwashers and automatic clothes washers can also increase the amount of water used in both urban and rural areas, depending on how efficiently they are used (Fig. 3-7). Rural residents are adopting a more urban lifestyle, and expectations for the same level of basic services are growing. This change is expected to lead to greater water use. In contrast, rural residents are still more directly affected by drought conditions and water shortages. They usually respond more rapidly by reducing water use, especially outdoors.

Other rural water uses

Electrical power generation

Generating electrical power withdraws the largest volume of water in Canada. Close to 60% of the water used in thermal power generation is consumed.

Hydroelectricity is the largest source of power in Canada, in 1996 accounting for close to 60% of the total power generated. All Canadian provinces except Prince Edward Island produce hydroelectric power. Quebec produces one-half of the hydroelectric power in Canada, and British Columbia, Manitoba, Ontario, and Newfoundland are also significant producers. Although hydroelectric projects have affected the environment by flooding valleys and altering stream flows below and above reservoirs, the largest of these projects are located outside the agricultural regions of Canada.

Hydroelectric energy depends upon the energy present in the force of falling water, but does not withdraw water from its source. Power plants fall into two main categories:

- storage plants, which rely on large reservoirs that store water during high flows and release it in a regulated way to generate power; such reservoirs are often

- used for other purposes, including recreation, flood control, and water supply
- run-of-river plants, which operate mainly on natural or regulated river flows.

Generating thermal electricity uses the heat energy from fuels (e.g., coal, natural gas, or uranium) to produce steam that drives a turbine coupled to a generator. Thermal power generation requires large quantities of water for condenser cooling. This water is eventually discharged to the environment in a heated state. In 1996, Ontario generated 55% of Canada's thermal power and accounted for almost 70% of its gross water use. Alberta ranked second (17%) but used proportionately less water, because water is recirculated at two of its thermal plants.

Rural municipal use

More than 2200 small communities (those with populations of less than 10 000) are scattered throughout the rural areas of Canada. About 80% of the people in these communities are served by municipal water systems. They withdraw about 84% less water than is withdrawn by agriculture and consume only about 15% of what they use. Watering lawns and gardens is a major consumptive use. Most of the rest is generally returned as wastewater after treatment. About 40% of municipal supply systems rely at least partly on groundwater.

Manufacturing

Manufacturing withdraws about twice as much water as agriculture. Most of this water is obtained directly by users through their own supply systems, and about 10% is provided through municipal systems. Manufacturers of paper, primary metals, and chemicals are by far the greatest users, accounting for almost 80% of water used for manufacturing in 1991. Food and beverage processing accounted for less than 6% that year. However, this value may grow as provinces expand the value-added processing of agricultural and other resource products.

About 10% of the water used in manufacturing is provided by wells, and the rest comes from surface supplies. Unlike for agriculture, only about 7% of the water used in manufacturing is consumed. The rest is discharged as wastewater of varying quality. Manufacturing also recycles water

internally, with almost as much water being reused as that being withdrawn from sources.

Mining, oil, and gas

Mining and the extraction of oil and gas are together one of the smallest users of water in rural areas, making withdrawals of less than 10% of those of agriculture. Water is consumed mainly through deep-well injection in prairie oil and gas fields and amounts to nearly 30%. Wastewater discharges are often high in suspended sediments, heavy metals, and acids.

Fisheries, aquaculture, and wildlife habitat

The use of water as habitat for fish and other wildlife is discussed in Chapter 7. *Aquaculture* is rising in importance in rural and coastal communities, and its continued success in the future depends on the availability of water of suitable quality. Further discussion of aquaculture is, however, beyond the scope of this report.

Recreation

Throughout Canada, governments and private groups have developed parks, recreation areas, cottage sites, and natural areas. Water is often an important feature of these areas, along with the recreational activities it supports, including boating, swimming, sailboarding, waterskiing, fishing, hunting, wildlife viewing, and sightseeing.

The growing interest in *ecotourism* and *agrotourism* (e.g., guest farms and ranches) offers rural Canadians opportunities to diversify and expand their businesses. The presence of water and the habitat it provides for fish and wildlife enhance these opportunities.

Central and eastern Canada, and much of British Columbia, enjoy a relative abundance of lakes, streams, and rivers suitable for water-based recreation. Though the Prairies and parts of the interior of British Columbia possess fewer high-quality water resources, residents still look to their lakes and streams for recreational opportunities. In the southern Prairies, storage reservoirs provide an important resource for developing both public parks and private cottage areas (see Box, p. 25).

Water bottling in Quebec—a case of competition

The water-bottling industry is booming in Quebec, directly and indirectly employing 5000 people and generating sales of \$75 million each year. But the rapid expansion of this industry has some citizens concerned that there won't be enough water to go around. They worry that the lack of regulatory controls on groundwater use will allow the bottling industry to take more than its fair share, using up water also needed for domestic use, agriculture, and other activities.

In the Quebec municipality of Franklin, a citizens' committee has formed to oppose a new water-bottling project. They argue that a similar project near Mirabel has affected the quantity and quality of water used by 85% of the people living within 8 kilometres of the commercial well. Many Franklin farmers depend on groundwater to irrigate their fruit crops. The aquifer also serves the domestic needs of two municipalities, two agri-food industries, and two campsites receiving 10 000 visitors each summer. With good reason, Franklin's citizens are asking if their groundwater resource is going to last. The problem is, no one knows for sure how much groundwater is there, how it is renewed, or how extraction activities like water bottling affect the resource.

In the face of public and media pressure, the government of Quebec imposed a moratorium on the water-bottling industry in December 1997, freezing all new requests for permits until a new policy was created to define water rights and management in Quebec. Members of the industry protest this action, saying that they bottle only a fraction (half a million cubic metres) of the total amount of groundwater used in Quebec each year, while the aquaculture industry uses 40% (100 million cubic metres). They also decry the polluting effect of agriculture and are asking for exclusive and protected zones for their industry so the quality of their product can be protected.

Which water use should have priority? Who should have the power to decide this? All parties concerned agree that legislation is needed to provide precise and fair rules that will protect both the quantity and quality of the groundwater resource.

M.C. Nolin, Agriculture and Agri-Food Canada



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Legislation and regulation of water use

In response to the growing demands for limited water supplies, most provinces have developed water rights legislation to regulate the withdrawal of surface water and groundwater for beneficial uses (see Box, p. 10). An exception to this occurs in Quebec and British Columbia, where the withdrawal of groundwater is not subject to licensing (see Box opposite). Another issue is the export of water. Although this topic is undergoing considerable debate, it is generally believed that water becomes an export commodity only when it is bottled. It is still unclear whether bulk or flowing-water exports are permitted under existing legislation.

Provincial legislation or regulations generally list water uses in order of importance, with domestic and municipal needs in first and second place. Domestic uses are generally exempted from legislation or from licensing. Use of water for other purposes without a licence or outside of licence conditions carries penalties. Water use legislation usually also contains clauses that allow provinces to revoke or suspend licences, collect information, and inspect facilities.

Besides meeting the requirements of water rights legislation, major water projects, such as irrigation and hydroelectric dams, must also comply with other federal and provincial statutory requirements. Among the major pieces of federal legislation that govern water development and use are the *Fisheries Act*, *Navigable Waters Protection Act*, *Canadian Environmental Protection Act*, and *Canadian Environmental Assessment Act* (see Chapter 11 for a description of these acts). Most provinces have developed environmental and health legislation, regulations, and guidelines that complement federal requirements related to environmental assessment and pollution control.



Conclusion

Of the many rural users of water, agriculture consumes the most. Because of its dependence on water for crop and livestock production, agriculture competes with other users when water resources are limited.

With the expansion of urban and rural communities and industry in many regions and the growing concern for resource stewardship and environmental protection, agriculture must be recognized as a wise user of water—one that uses resources efficiently with little waste and returns water to its cycle in a state that is suitable for other users. Such wise use is motivated and supported by many factors, including consumer demand for green agricultural products, the growing environmental ethic of farmers, environmentally sound technologies and management practices, and environmental policy and regulation.

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Recreational use of Lake Diefenbaker, Saskatchewan

Lake Diefenbaker, created by the Gardiner and Qu'Appelle dams on the South Saskatchewan River, is a multi-purpose reservoir. Besides serving as a high-quality source of water for major irrigation projects, hydroelectric power generation, and domestic and municipal needs, it is an important recreational resource for residents of southern Saskatchewan.

Along the shores of the reservoir are located three provincial parks, four regional parks, several resort villages, two golf courses, and a yacht club. The reservoir also offers opportunities for recreational fishing and waterfowl viewing and hunting. Effort is made to maintain high and stable lake levels in July and August to meet the needs of recreational users and to maintain stable flows in the river below Gardiner Dam.

E. Kienholz, Agriculture and Agri-Food Canada

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4. Understanding Water Quality

D.B. Harker, P.A. Chambers, A.S. Crowe, G.L. Fairchild, and E. Kienholz

Water quality is a major environmental concern in Canada. People want the assurance that water in Canada is safe for their health, recreation, and industry, as well as for the proper functioning of ecosystems. In the 1960s and 1970s, when evidence of the health risks of using organochlorine pesticides such as DDT began mounting, the public pressured agricultural policy makers to remove these chemicals from the market. The Canadian public continues to make it

- Agriculture contributes to declining water quality. However, it is difficult to measure this contribution and to identify the locations involved because of the high cost of monitoring; the seasonal and spatial variability of contaminant movement and water flow; the large number and diversity of farms and farming practices; and regional differences in topography, soils, and climate.
- Agriculture affects water quality mainly through the movement of sediments, nutrients, pesticides, and pathogens off farmland and into water by surface runoff, leaching into groundwater or tile drains, or release to the atmosphere. Soil conditions are a major factor in how water moves through the farm landscape. Farm management practices influence both soil health and the potential for contaminants to accumulate in soil and move into water. The aim of sustainable agriculture is to use water in a way that meets economic goals while conserving water resources and limiting the contributions of potential pollutants.
- Agriculture itself depends on the availability of good-quality water for its many uses. Poor-quality water has the potential to impair the health of crops, livestock, and farm families and to lower agricultural productivity.
- National monitoring of water quality has been largely discontinued, and many provincial monitoring programs have been cut back during the 1990s. Assessment of water quality must rely on the results of regional or watershed projects, often illustrated by specific case studies and field research.

Introduction

Over the past 40 years Canadian farms have grown fewer, larger, and more productive. This transformation was made possible by greater mechanization, the use of mineral fertilizers and crop protection chemicals (e.g., herbicides, insecticides, and fungicides), new and better crop varieties, and innovative farming practices. Over time, some of these advances have clearly compromised environmental health, including water quality.

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Highlights

- Water quality is a major environmental concern of Canadians. Good water quality is hard to define because it depends on the intended use of the water and on society's perception of what level of risk is acceptable.
- Water quality standards, such as those defined by the Canadian Environmental Quality Guidelines, are typically based on concentrations of certain chemicals. A more holistic approach to assessing water quality is to more equally consider all properties of a water body—physical, chemical, and biological.
- Agriculture contributes to declining water quality. However, it is difficult to measure this contribution and to identify the locations involved because of the high cost of monitoring; the seasonal and spatial variability of contaminant movement and water flow; the large number and diversity of farms and farming practices; and regional differences in topography, soils, and climate.
- Agriculture affects water quality mainly through the movement of sediments, nutrients, pesticides, and pathogens off farmland and into water by surface runoff, leaching into groundwater or tile drains, or release to the atmosphere. Soil conditions are a major factor in how water moves through the farm landscape. Farm management practices influence both soil health and the potential for contaminants to accumulate in soil and move into water. The aim of sustainable agriculture is to use water in a way that meets economic goals while conserving water resources and limiting the contributions of potential pollutants.
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Water quality is a major environmental concern of Canadians. People want the assurance that water in Canada is safe for their health, recreation, and industry, as well as for the proper functioning of ecosystems. In the 1960s and 1970s, when evidence of the health risks of using *organochlorine pesticides* such as DDT began mounting, the public pressured agricultural policy makers to remove these chemicals from the market. The Canadian public continues to make it

clear that water quality should be a major concern in agricultural practice, and that environmental policy and programs are needed to protect our water resources. Protecting water quality is also a vital component of sustainable agriculture, and balancing agricultural growth with a clean environment is an important part of doing business in today's world marketplace.

Risk and water quality

With respect to water quality, risk assessments are science-based estimates of the risk faced by a population (human or other) or an ecosystem when exposed to a particular substance or natural phenomenon. Attitudes toward acceptable risk greatly affect how people interpret the same water quality information. Individuals may differ in what they consider to be acceptable water quality, even for the same water and intended use.

Some people take a position of *zero tolerance*, holding that no amount of an unnatural substance (e.g., pesticide) or elevated amount of a natural substance (e.g., nitrate, phosphorus) in water is acceptable. Others point out that all of nature uses water to absorb and transport waste products and nutrients, so humans ought to be able to do the same thing in a responsible way. They believe that a demand for zero tolerance is unreasonable and are prepared to accept an approach that follows guidelines to maintain contaminants at levels below which our lives and the health of ecosystems are at reasonable risk. Yet others feel that this attitude does not address concerns about the possible *additive* and *synergistic effects* of multiple trace contaminants. They feel it relies too heavily upon traditional approaches instead of ones that might deal better with the actual risk.

Risk assessment is at best an imprecise science. It combines information on the level of exposure to a substance, as well as its toxicity, to characterize what is likely to happen to humans or other animals that may be exposed. Confusion often arises from the scientific uncertainties associated with this assessment. People tend to take risks when they are self-imposed or well known, but resist involuntary risk. In the absence of dependable and consistent field data at a broad scale (see the following discussion on monitoring

water quality), experts increasingly rely on mathematical tools, such as formulas and models, to calculate risk.

For example, models have been developed to simulate the movement and fate of pesticides in the subsoil and predict concentrations over time and depth. Although these tools are useful, results can seldom be used to say for certain whether real problems exist, unless they are validated using actual data. However, they can be useful for

- estimating trends over time
- making regional comparisons
- spotlighting areas where further investigation is needed
- meeting the ever-growing requirements under international agreements to report on Canada's environmental performance.

Defining and measuring water quality

Pinning down a definition of water quality is difficult. Water quality is usually defined in terms of what water is used for. Standards for the quality of drinking water may be quite different from those for water used to irrigate field crops or to support aquatic life.

Methods used for measuring water quality have often taken a chemical approach. Chemical indicators of water quality include measurements of acidity, salinity, various forms of oxygen, phosphorus, nitrogen, pesticides, and heavy metals. The *Canadian Environmental Quality Guidelines* rely heavily on this type of approach to define the acceptable quality of water used for drinking, recreation, irrigation, and other uses (see Box). However, the main criteria used to assess water quality for drinking and recreation are the microbiological guidelines found in Health Canada's *Guidelines for Canadian Drinking Water Quality*. Maximum concentrations specified in the guidelines generally incorporate a safety factor 10 to 1000 times greater than test results indicate. Thus, there is generally no absolute line between good- and poor-quality water.

Some people view Canadian and similar guidelines as too liberal, preferring to operate under the *precautionary principle*. This principle purports that precautionary measures should be

Canadian Environmental Quality Guidelines

Canadian water, sediment, soil, and tissue quality guidelines are developed to protect and sustain specific uses of land, water, and biota. They provide direct measures of sustainability that can be used to assess overall resource quality and ecosystem health. The *Canadian Environmental Quality Guidelines*, developed by Environment Canada under the auspices of the Canadian Council of Ministers of the Environment, recommend levels in the environment that should not be exceeded in order to prevent negative environmental effects. They include the *Canadian Water Quality Guidelines*, which have been developed for various substances in raw (untreated) drinking water, recreational water, water used for agricultural purposes, and water to support aquatic life. Also included are guidelines developed by Health Canada for finished (treated) drinking water, entitled *Guidelines for Canadian Drinking Water Quality*. The recently completed 1999 *Canadian Environmental Quality Guidelines* includes about 550 guidelines for more than 200 priority substances and parameters in Canada.

The *Canadian Water Quality Guidelines* are used by provincial, territorial, and federal agencies to assess water quality problems and to manage competing uses of water resources. They are based on the best scientific information available at the time and are subject to periodic re-evaluation as new information becomes available. Priorities for developing new guidelines are established annually, including the continued development of guidelines for in-use priority pesticides and other emerging agriculture-related parameters.

Water guidelines for several substances commonly derived from agriculture are given below.

Canadian water quality guidelines for selected substances

Substance	Drinking water quality guideline (Health Canada)	Water quality guideline for protecting aquatic life (freshwater)	Agriculture water quality guideline for irrigation	Agriculture water quality guideline for watering livestock
Bacteria* (no./100 mL)				
Total coliform	10	-	1000	-
Fecal coliform	0	-	100	-
Nitrate-nitrogen (mg/L)	10	-	-	100 (nitrate+nitrite)
Nitrite (mg/L)	-	0.06	-	10
Pesticides (µg/L)				
atrazine	5(1)	1.8	10	5
cyanazine	10(1)	2.0	0.5	10
diazinon	20	-	-	-
diclofop-methyl	9	6.1	0.18	9
glyphosate	280(1)	65	-	280
metolachlor	50(1)	7.8	28	50
metribuzin	80(1)	1.0	0.5	80
simazine	10(1)	1.0	0.5	10

* Microbiological guidelines have been simplified; see guidelines for details.

(1) = Interim guideline.

Source: *Canadian Environmental Quality Guidelines*, Canadian Council of Ministers of the Environment, 1999

R.A Kent, Environment Canada

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Units used in this report

Concentrations

Chemical concentrations in water are expressed in this report in various units per unit volume, such as micrograms or milligrams of the substance in one litre of water. Another common way of expressing concentrations is in parts per million (one part of the chemical per million parts of chemical plus water) or parts per billion, where

1 milligram per litre (1 mg/L) = 1 part per million (ppm)

1 microgram per litre (1 µg/L) = 1 part per billion (ppb)

Average concentrations are often given as time-weighted averages, which is the total mass of a substance over a period divided by the total amount of water that flowed during that time. The amount of a substance flowing over a period can be expressed in terms of mass per unit area, such as grams, kilograms, or tonnes per hectare.

The term *loading rate* refers to the amount of a substance that is discharged or lost from a farm or watershed over a period. It is expressed in terms such as grams per year, or kilograms per hectare per year.

Units

The units used in this report to define water quality generally refer to the concentration of nitrogen (N) present as nitrate (NO₃). It is expressed as the concentration of nitrate-nitrogen (NO₃-N). In European water quality standards, nitrate refers to the concentration of the total nitrate ion (NO₃⁻). The figures in this report are for a higher standard, which is nitrate-nitrogen. The European standard of 50 milligrams of NO₃-N per litre of water is equivalent to the North American standard of 45 milligrams of nitrate-nitrogen (NO₃-N) per litre of water.

taken when an activity poses a risk to the environment or human health, whether or not sufficient scientific research has been conducted to conclusively support taking these measures. This view leads to more stringent guidelines, such as those found in the European Commission's 1980 *Drinking Water Directive*. This directive prescribes the maximum admissible concentration as

- 0.1 micrograms per litre for individual pesticides (Canadian guidelines include values as different as 5 micrograms per litre for atrazine and 280 micrograms per litre for glyphosate)
- a total of 0.5 micrograms per litre for all pesticides combined (there is no provision for combined pesticides in the Canadian guidelines)
- 50 milligrams per litre for nitrate ion (equal to 11 milligrams of nitrate-nitrogen and thus similar to the Canadian guideline of 10 milligrams of nitrate-nitrogen per litre)
- 5000 micrograms per litre for phosphorus (the Canadian guidelines do not set a limit). (See Box, p. 29)

Chemical indicators are only one way to assess the state of water quality. There is growing recognition that assessment of water quality must take a more holistic approach, considering all the properties of a water body—not only physical and chemical, but biological and ecological as well (Fig. 4-1). For example, the health of the biological community supported by a water body can be an indirect measure of the water's chemistry.

Biological indicators can reflect the combined effects of pollutants, changes in habitat, and other environmental impacts that monitoring chemical and physical properties alone cannot reveal. Examples of biological indicators of water quality include

- *aquatic indicator species* (e.g., examining the health of sensitive species)
- *biodiversity* (e.g., the number of species and the numbers of individuals of each species)
- *functional diversity* (e.g., assessing the range of species that perform different ecosystem functions, such as grazing on algae and bacteria, preying on other animals, etc.)



Figure 4-1
Holistic approach to
assessing water quality

- ecosystem properties (e.g., primary production and decomposition).

Human health is another angle in assessing water quality. For example, large population studies may shed light on possible synergistic or additive effects of contaminated water on human health. Age studies may show that people at certain life stages are more susceptible than others to the effects of contaminated water or are more likely to manifest these effects. However, such studies often involve complex analyses, and the effects of many chemical interactions are still poorly understood.

Monitoring water quality

To meet the public demand for better water quality in the 1970s, provincial and federal agencies initiated monitoring programs involving regular sampling and analysis of groundwater and surface water. This analysis generally focused on sediments, nutrients (especially nitrate, ammonium, and phosphate), major ions and metals, and sometimes pesticides and bacteria. Monitoring was also used to assess the effects of these contaminants on fish and wildlife.

Results of monitoring programs are used to make management decisions related to water quality based on knowledge of the nature and distribution of water pollution problems. Reliable time series data can be used to

- assess the health of aquatic ecosystems
- provide early warning and detection
- evaluate the performance of pollution abatement programs.

Without adequate monitoring data and knowledge of both watersheds and watercourses, scientists and managers can only speculate about water quality problems, probable causes, likely consequences, and the adequacy of management measures to protect and restore water quality.

Monitoring is often uniquely tailored to specific issues, the area of surveillance, and financial and time constraints. *Reconnaissance monitoring* usually involves the periodic sampling of waters over a large area and a long time, and the analysis of a wide variety of water quality parameters. It is valuable for identifying detrimental changes from natural conditions over time. *Objective monitoring* responds to a known problem and usually targets

Approximate current cost of water analysis

Test substance	Cost per analysis
Nutrients ($\text{NO}_3^- + \text{NO}_2^- + \text{NH}_4^+$)	\$1.50
Nutrients (total - P , O_2)	\$1.50
Bacteria (total coliform, 2 cell)	\$1.50
Pesticides (organochlorines)	\$15.00

A. Crowe, Environment Canada

specific chemicals. Such sampling covers a small area and is limited to a shorter period.

The cost of monitoring is quite high, involving

- network design and management
- purchase of sampling equipment (e.g., pumps and bottles)
- operation of boats for surface water sampling
- installation of wells for groundwater sampling
- sample preparation, transportation, and storage
- laboratory analysis (see Box)
- salaries and training of specialized staff
- costs of data processing
- interpretation and reporting of results.

Most federal and provincial agencies have cut back on programs for routine reconnaissance monitoring in recent years. Today, monitoring programs are usually targeted at specific problems in particular locations in response to public concerns about real or perceived problems. Federal and provincial governments currently sponsor regional and local monitoring. Some municipalities monitor surface water and wells, usually through local health departments. As well, many industries are obliged to monitor water quality as a condition of their licence to operate. Many monitoring programs are now being undertaken through partnerships among universities, municipalities, farm organizations, industry, public interest



Surface water sampling



Groundwater sampling

Units used in this report

General

Chemical concentrations in water are expressed in this report in terms of mass per unit volume, such as micrograms or milligrams of the substance in one litre of water. Another common way of expressing concentrations is in parts per million (one part of the chemical per million parts of chemical plus water) or parts per billion, where

1 milligram per litre (1 mg/L) = 1 part per million (ppm)

1 microgram per litre (1 µg/L) = 1 part per billion (ppb).

Average concentrations are often given a flow-weighted mean, which is the total mass of a substance over a period divided by the total amount of water that flowed during that time. The amount of a substance leaving a farm field or a watershed may be expressed in terms of mass per unit area, such as grams, kilograms, or tonnes per hectare.

The term *loading* refers to the amount of a substance that is discharged or lost from a farm or watershed over a period. It is expressed in units such as grams per year, or kilograms per hectare per year.

Nitrate

The term nitrate as used in this report to define water quality generally refers to the concentration of nitrogen (N) present as nitrate (NO_3^-), also expressed as the concentration of nitrate-nitrogen (NO_3^- -N). In European water quality standards, nitrate refers to the concentration of the total nitrate ion (NO_3^-). Because the nitrate ion has a higher atomic weight than nitrogen alone, the European standard of 50 milligrams of NO_3^- ion per litre of water is roughly equivalent to the North American standard of 10 milligrams of nitrate-nitrogen (NO_3^- -N) per litre of water.

taken when an activity poses a risk to the environment or human health, whether or not sufficient scientific research has been conducted to conclusively support taking these measures. This view leads to more stringent guidelines, such as those found in the European Commission's 1980 *Drinking Water Directive*. This directive prescribes the maximum admissible concentration as

- 0.1 micrograms per litre for individual pesticides (Canadian guidelines include values as different as 5 micrograms per litre for atrazine and 280 micrograms per litre for glyphosate)
- a total of 0.5 micrograms per litre for all pesticides combined (there is no provision for combined pesticides in the Canadian guidelines)
- 50 milligrams per litre for nitrate ion (equal to 11 milligrams of nitrate-nitrogen and thus similar to the Canadian guideline of 10 milligrams of nitrate-nitrogen per litre)
- 5000 micrograms per litre for phosphorus (the Canadian guidelines do not set a limit). (See Box, p. 29)

Chemical indicators are only one way to assess the state of water quality. There is growing recognition that assessment of water quality must take a more holistic approach, considering all the properties of a water body—not only physical and chemical, but biological and ecological as well (Fig. 4-1). For example, the health of the biological community supported by a water body can be an indirect measure of the water's chemistry.

Biological indicators can reflect the combined effects of pollutants, changes in habitat, and other environmental impacts that monitoring chemical and physical properties alone cannot reveal. Examples of biological indicators of water quality include

- *aquatic indicator species* (e.g., examining the health of sensitive species)
- *biodiversity* (e.g., the number of species and the numbers of individuals of each species)
- *functional diversity* (e.g., assessing the range of species that perform different ecosystem functions, such as grazing on algae and bacteria, preying on other animals, etc.)

Chemical parameters

Acidity, salinity, oxygen, nitrogen, phosphorus, heavy metals

Physical parameters

Temperature, turbidity, sedimentation

Water Quality

Biological/ecological parameters

Bacteria, aquatic indicator species, productivity, health of biological communities, biodiversity, functional diversity, habitat shifts

Human health parameters

Additive and synergistic effects, age studies, regional studies

Figure 4-1
Holistic approach to
assessing water quality

- ecosystem properties (e.g., primary production and decomposition).

Human health is another angle in assessing water quality. For example, large population studies may shed light on possible synergistic or additive effects of contaminated water on human health. Age studies may show that people at certain life stages are more susceptible than others to the effects of contaminated water or are more likely to manifest these effects. However, such studies often involve complex analyses, and the effects of many chemical interactions are still poorly understood.

Monitoring water quality

To meet the public demand for better water quality in the 1970s, provincial and federal agencies initiated monitoring programs involving regular sampling and analysis of groundwater and surface water. This analysis generally focused on sediments, nutrients (especially nitrate, ammonium, and phosphate), major ions and metals, and sometimes pesticides and bacteria. Monitoring was also used to assess the effects of these contaminants on fish and wildlife.

Results of monitoring programs are used to make management decisions related to water quality based on knowledge of the nature and distribution of water pollution problems. Reliable time series data can be used to

- assess the health of aquatic ecosystems
- provide early warning and detection
- evaluate the performance of pollution abatement programs.

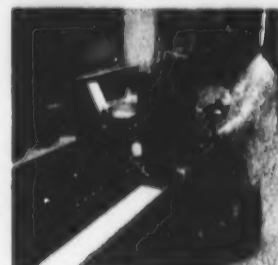
Without adequate monitoring data and knowledge of both watersheds and watercourses, scientists and managers can only speculate about water quality problems, probable causes, likely consequences, and the adequacy of management measures to protect and restore water quality.

Monitoring is often uniquely tailored to specific issues, the area of surveillance, and financial and time constraints. *Reconnaissance monitoring* usually involves the periodic sampling of waters over a large area and a long time, and the analysis of a wide variety of water quality parameters. It is valuable for identifying detrimental changes from natural conditions over time. *Objective monitoring* responds to a known problem and usually targets

Approximate current cost of water analysis

Test substance	Cost per analysis
Nutrients ($\text{NO}_3 + \text{NO}_2, \text{NH}_4$)	\$ 5.60
Nutrients (total - P_2O_4)	\$4.90
Bacteria (fecal coliform, <i>E. coli</i>)	\$15.00
Pesticides (organochlorines)	\$287.00

A. Crowe, Environment Canada



specific chemicals. Such sampling covers a small area and is limited to a shorter period.

The cost of monitoring is quite high, involving

- network design and management
- purchase of sampling equipment (e.g., pumps and bottles)
- operation of boats for surface water sampling
- installation of wells for groundwater sampling
- sample preparation, transportation, and storage
- laboratory analysis (see Box)
- salaries and training of specialized staff
- costs of data processing
- interpretation and reporting of results.

Most federal and provincial agencies have cut back on programs for routine reconnaissance monitoring in recent years. Today, monitoring programs are usually targeted at specific problems in particular locations in response to public concerns about real or perceived problems. Federal and provincial governments currently sponsor regional and local monitoring. Some municipalities monitor surface water and wells, usually through local health departments. As well, many industries are obliged to monitor water quality as a condition of their licence to operate. Many monitoring programs are now being undertaken through partnerships among universities, municipalities, farm organizations, industry, public interest



Surface water sampling



Groundwater sampling

groups, and government agencies, to share costs and make better use of results.

National monitoring

The Water Survey of Canada was established in 1908 to collect, analyze, and distribute data on water quantity, including flow rates for rivers and streams and water levels in lakes and rivers. The federal government became involved in water quality monitoring in 1934, emphasizing water used by municipalities and industry. The growing awareness of environmental issues among Canadians in the 1960s led to a national water quality network being established to assess the impact of human activities on rivers and lakes, not only in agricultural areas but also throughout the country. Data collected across Canada were compiled by Environment Canada in the National Water Quality Database (NAQUADAT). This database provided a comprehensive overview of the quality of Canadian surface waters and was used with national water quality guidelines to establish water quality objectives for lakes and rivers.

The federal government monitors the quality of surface water under the *Canada Water Act* and the *Canadian Environmental Protection Act* through Environment Canada. Since the late 1970s, Environment Canada's role in monitoring water quality has diminished markedly, with remaining programs focused on

- boundary and transboundary waters, including the Great Lakes and its connecting channels (e.g., Niagara, Detroit, and St. Clair rivers)
- major rivers crossing the boundaries of the Prairie provinces (e.g., North and South Saskatchewan rivers)
- cases that fit closely with the requirements of pertinent federal legislation and with Environment Canada's mandate, science priorities, and ecosystem initiatives (e.g., support of federal statutes dealing with fisheries, pulp and paper, and mining; support for ecosystem initiatives within the Great Lakes, St. Lawrence River basin, the Fraser River basin, Atlantic Canada, and the North).

In some regions, provincial governments have taken over monitoring the water quality of inland

ivers and lakes in areas in which they have an interest. National coverage is therefore incomplete and inconsistent. At present, no single agency operates a general, nationally integrated monitoring program for water quality in Canada.

The federal government generally does not undertake programs to routinely assess the quality of groundwater, mainly because groundwater is legislated as a provincial resource. The federal government does become involved in groundwater concerns when they relate to federal responsibility or federal interest, such as when groundwater contamination threatens to cross an international border (e.g., the Abbotsford–Sumas Aquifer in British Columbia; see Box, p. 63). In such cases, groundwater monitoring is undertaken at a specific location by the regional offices of Environment Canada in collaboration with provincial government agencies. Natural Resources Canada's Geological Survey of Canada is involved in groundwater quantity research and monitoring in several regions of Canada.

Provincial and local monitoring

Most provinces and some local organizations are involved in monitoring water quality or flow rates in rural areas. A few examples of recent activities are presented (see Box opposite).

Agricultural effects on water quality

Agricultural activities modify natural ecosystem functions to optimize the production of food and fibre. As these modifications take place, the broader environment may be negatively affected, including a decline in water quality in downstream and receiving water bodies (see Box, p. 34). Assessing these effects, particularly related to water quality, is complicated by the

- difficulty in tracing chemicals back to nonpoint sources such as farmland
- high cost of monitoring
- large number and diversity of farms, soil types, and farming practices
- time lag between when a substance is applied to the land and when its environmental effects may become evident.

Provincial and local programs to monitor water quality in Canada

The following examples are just a few of the many water quality monitoring activities that are being undertaken across the country by provincial and local governments, river basin authorities, and universities. They have been selected to provide the reader with an idea of the scope of different monitoring programs.

British Columbia

Provincial agencies are cooperating with Environment Canada and U.S. agencies to conduct a groundwater monitoring program of the transboundary Abbotsford–Sumas aquifer in southern British Columbia. A network of 40 wells has been monitored monthly since the late 1970s. Analysis has focused on nitrate levels in the groundwater, but samples are occasionally analyzed for pesticides. Reduced funding in recent years has resulted in a reduction in the number of wells being sampled and the frequency of sampling.

Prairie Provinces

Between 1994 and 1997, the Canada–Alberta Environmentally Sustainable Agriculture Agreement (CAESA) provided federal and provincial support for monitoring to determine the impact of agriculture on water quality in Alberta. Wells, dugouts, streams, and lakes were checked for nutrients, pesticides, and bacteria. Federal, provincial, private sector, and university researchers were involved. Monitoring continues under other programs.

Central Canada

Ontario has 200 stations to monitor the water quality of streams and rivers, down from a peak of about 2700 stations in the 1970s. Sampling is currently carried out eight times a year, and the water is analyzed for major ions, including nitrate. Pesticide analysis is not done routinely. A subset of this monitoring network focuses on five watersheds: those of the Grand, Thames, Saugeen, Humber, and Don rivers. These watersheds are monitored in more detail, including pesticide analysis of surface water samples. Provincial agencies do not publish long-term trend data or assessments.

Quebec is one of the few provinces that has maintained a year-round, long-term monitoring program since the late 1970s, at a network of water quality stations. Detailed reports on water quality and land use are published.

Atlantic Provinces

Prince Edward Island's Department of the Environment carried out a 3-year (1996–1998) monitoring program consisting of three components:

- regular sampling of 30 wells located in areas of intense agriculture, targeting pesticides
- regular sampling of 30 wells located across the province in different land use areas (agricultural, residential, industrial, urban) to assess the state of groundwater quality
- sampling of wells installed by the department to identify and track the movement and persistence of target pesticides; these wells were installed in fields where a known pesticide was applied, to assess the potential for pesticides to contaminate groundwater under field conditions.

The program is expected to be extended, focusing on different pesticides. (Leachable pesticides targeted in the first program were not detected, so the new program will target pesticides, mainly fungicides, used in the highest volumes.)

H. Liebscher, Environment Canada

D.O. Trew, Alberta Environment

G.S. Bowen, Ontario Ministry of Environment and Energy

J. Painchaud, Quebec Ministry of the Environment

J.P. Mutch, Prince Edward Island Department of Technology and Environment

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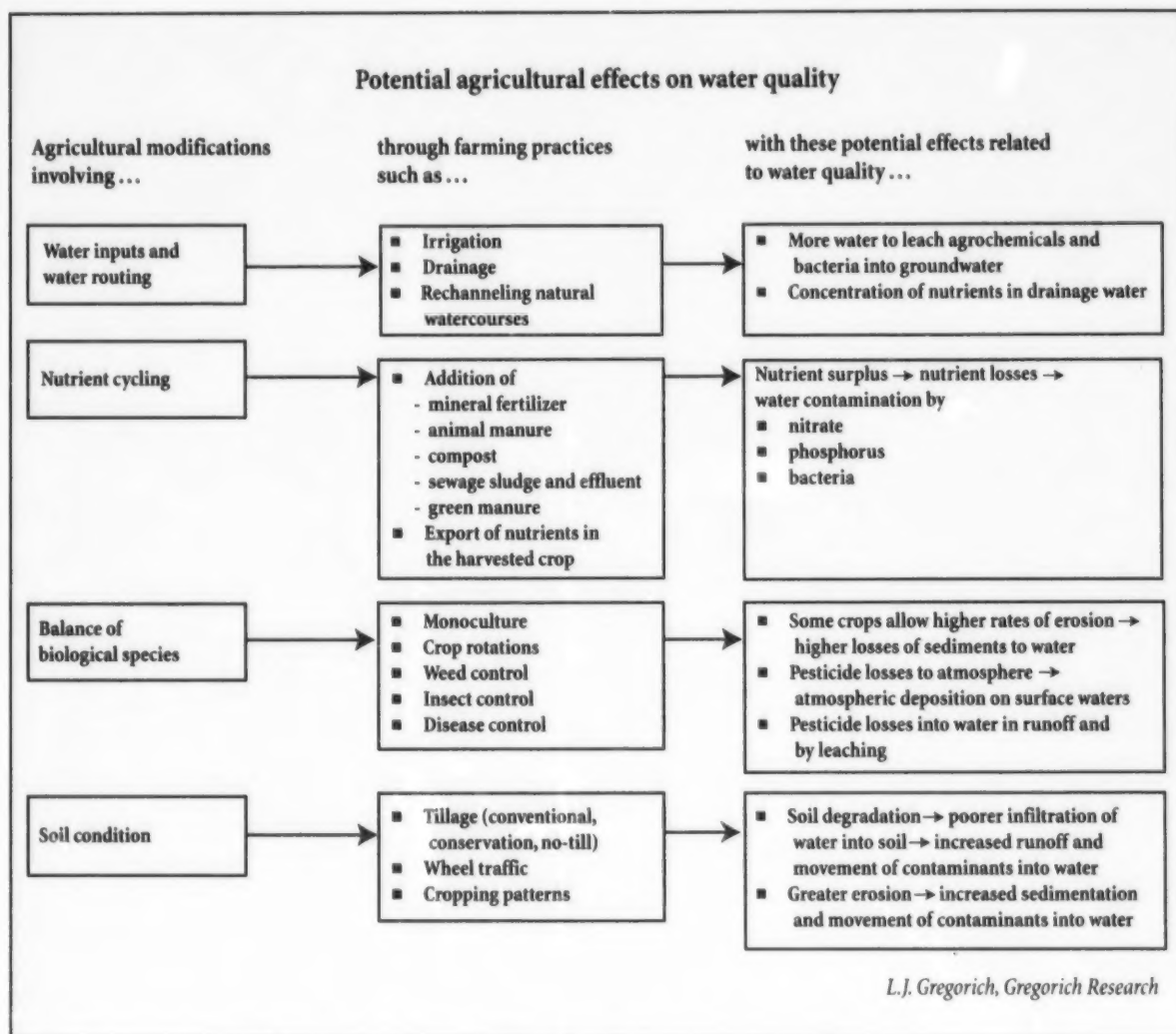
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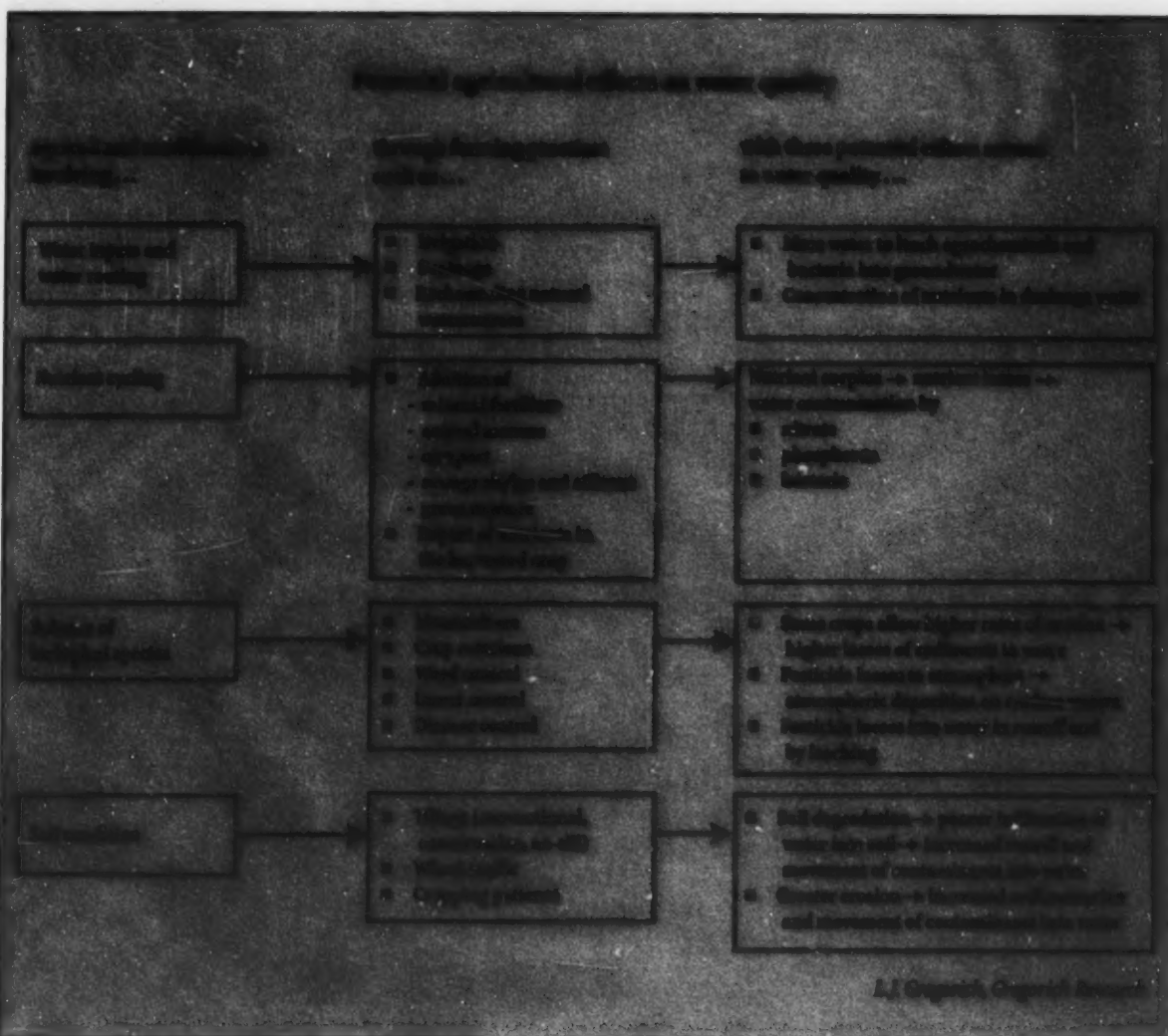
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Although these factors make it difficult to reach a consensus of opinion on the actual effects of agriculture on water quality, it is known that the main agents of declining water quality that derive from agriculture are soil particles, crop nutrients, pesticides, and bacteria. The evaluation of water quality presented in this report pertains to these substances. How, and to what extent, these substances move off farmland into surface and groundwater is governed largely by agricultural practices that affect the movement of water through the landscape (e.g., irrigation and drainage) and soil condition (e.g., tillage and cropping practices).

Soil condition

Agricultural soils are a major factor in determining how much water leaves farmland and how it leaves. Soils have natural characteristics that determine how well they receive and hold water. For example, water readily *infiltrates* (seeps into) coarse-textured, sandy soils, but these soils do not retain much water. Fine-textured soils, like clays, are less *permeable* to water, but these soils generally have a good capacity to store water.



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Agricultural management practices also influence a soil's role in determining water quality. Some tillage and cropping practices can degrade the quality of soil, making it less permeable to water and more vulnerable to erosion, both of which can contribute to declining water quality. Others can maintain or build up soil quality and help to control the agricultural effects on downstream water quality. Thus, management practices that are directed at curbing the decline of water quality arising from agriculture are often centred on soil management (see Chapter 8).

Sediments

Sediments generally consist of soil particles that enter water as a result of soil erosion. Erosion is a process by which soil is moved from one area to another. Although this process occurs naturally, agriculture can accelerate it by

- removing the natural vegetation that protects the soil and replacing it with cultivated crops, which leave more soil exposed to the elements
- altering the soil's structure so that it can absorb less water and is more prone to erosion.

When soil is moved into water bodies, it can significantly alter the quality of that water. Three types of erosion contribute to declining water quality:

- *Wind erosion*: wind picks up soil particles and often deposits them on the surface of water bodies.
- *Tillage erosion*: the action of tillage often moves soil to downslope sites in a field where it may be more vulnerable to water erosion.
- *Water erosion*: the most important erosive process associated with declining water quality. Water moving along the soil's surface picks up soil particles, especially fine ones, and carries them to watercourses.

Much of the soil that reaches surface waters remains in suspension (*suspended sediment*), affecting the *turbidity* of the water. The muddy brown colour of rivers sometimes seen during spring snowmelt and after heavy summer rainfall provides a vivid picture of the magnitude of sediment loadings of surface waters. After such events, the turbidity of lakes, rivers, and streams

can be high enough to lower the water's fitness for drinking and make it less suitable for aquatic plants and animals.

Sediments accumulating at the bottom of streams may alter the stream's *flow capacity*, increasing the risk of flooding. Sedimentation may also

- reduce the storage capacity of reservoirs and dugouts
- reduce the water depth of wetlands
- degrade the spawning grounds of some species of fish.

Mineral fertilizers, pesticides, plant residues, animal manure, and, in some cases, pathogenic organisms, can be carried off farmland by eroded soil particles and surface runoff, further polluting downstream waters. Thus, soil erosion and the resulting sedimentation are important considerations in examining and protecting water quality.

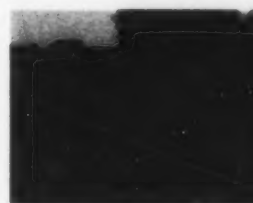
Controlling the entry of soil particles and attached substances into surface waters is largely a matter of controlling soil erosion. A recent national assessment of the change in the risk of erosion between 1981 and 1996 showed that the risk of

- water erosion on cropland in the Prairie provinces, Ontario, and New Brunswick dropped by differing amounts (Fig. 5-1, p. 44)
- wind erosion on prairie cropland fell by 30%
- tillage erosion on Canadian cropland dropped by 22%.

These results suggest that the volume of sediments carried from farmland to surface waters decreased, although perhaps not in exactly the same proportion because of marked differences across the country in the overland movement of soil.

Nutrients

Nutrients are chemical elements, such as nitrogen, phosphorus, and potassium, that are needed by plants for proper growth. These elements occur naturally and are made available to vegetation through precipitation, the physical and chemical weathering of rock and soil minerals, and the decomposition of organic matter (e.g., dead plants and animals). They can also be supplied as a result of human activity, particularly that related to agriculture, the discharge of industrial and



Sediment loading of a river

Nitrogen balances of OECD countries

The difference between the amount of nitrogen applied to the land and that removed by crops can be a surplus or a deficit. Surpluses can lead to losses of nitrogen to the environment. According to the records of the Organization for Economic Co-operation and Development (OECD), nitrogen surpluses in OECD countries are generally on the decline. This is not the case in Canada, where production of crops with a high demand for nitrogen is on the rise and increasing livestock production is generating more nitrogen in manure. However, Canada's mean nitrogen surpluses are still low when compared with the United States and Europe, as shown in the following table.

Average nitrogen surplus for
selected OECD countries
(kilograms per hectare per year)

Country	1985-1987	1995-1997	Percent change
Canada	7	14	113
Denmark	154	119	-23
France	59	53	-10
Japan	98	89	-9
New Zealand	5	6	27
United States	25	31	24

Source: McRae et al., 2000

Source: McRae et al., 2000

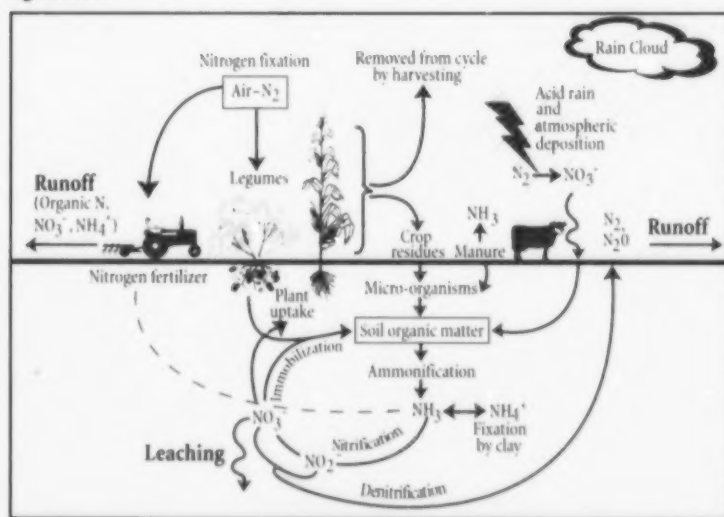
municipal waste, and atmospheric emissions. Nutrient loading is often considered the most serious environmental effect on water quality associated with agriculture.

To maintain crops of high yield and good quality, farmers have for years added plant nutrients to the soil, mainly in the form of animal manure, plant or animal residues, mineral fertilizers, and the plowdown of legumes. About 3.5 million tonnes of mineral fertilizer and 2 million tonnes of sewage sludge are applied to agricultural land each year. In addition, livestock produce about 300 million tonnes of manure each year in Canada, and most of it is applied to cropland. However, given the large area of Canada's cultivated land (more than 30 million hectares), these quantities are relatively small compared with many countries, especially those in Europe (see Box).

Nutrients held in the soil (e.g., nitrogen, Fig. 4-2) can

- be taken up by crops and removed from agricultural land when a portion of the crop is harvested
- remain bound to soil particles, organic matter, and crop residues, to be used by soil microbes or future crops, or carried off by water erosion
- be dissolved in water and carried out of the soil by leaching, tile drainage, or surface runoff.

Figure 4-2
Nitrogen cycling in
agriculture



If the amount of each nutrient in the soil is greater than the amount taken up by the crop, there is a risk that surplus nutrients will move off farmland into groundwater or surface waters. This risk is greatest under wet conditions and if the soil has a low capacity to bind chemicals, as is the case for coarse-textured soils like loamy sands. Areas where water is at risk of being contaminated by nitrogen often feature crops with high nitrogen needs and thus high applications of nitrogen fertilizer (see Box on residual nitrogen). Areas of intensive livestock production often have high levels of soil nutrients, particularly phosphorus, because of the heavy application of animal manure to the land.

Nitrogen becomes available for plant use when it is in soluble form, mainly nitrate. Nitrate in the soil may dissolve in water and leave farmland in surface runoff or leach below the root zone into

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Average nitrogen surplus for selected OECD countries (kilograms per hectare per year)

Country	1985-1987	1995-1997	Percent change
Canada	7	14	113
Denmark	134	119	-23
France	39	33	-16
Japan	64	60	-4
New Zealand	5	6	27
United States	25	31	24

Source: McKee et al., 2000

Source: McKee et al., 2000

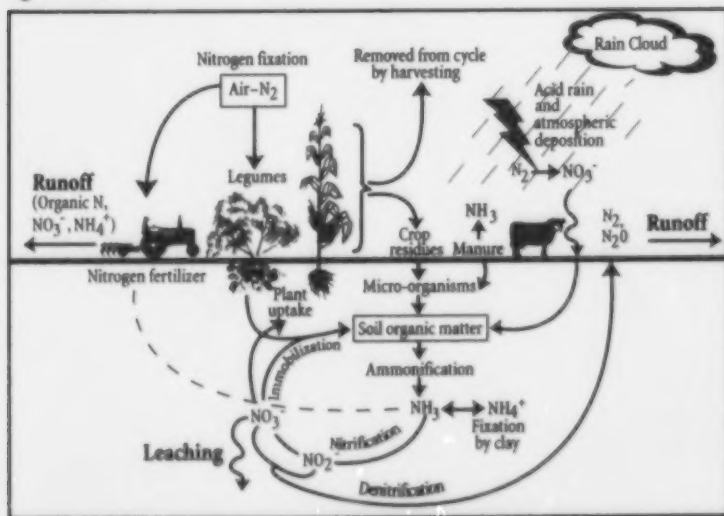
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Residual nitrogen

Residual nitrogen is the amount of nitrogen in soil beyond the needs of crops or their ability to absorb it. This nitrogen has the potential to move off farmland into neighbouring waters or leach into groundwater or tile drainage water. In a recent national assessment of residual nitrogen, Canadian farmland was assigned to one of four classes:

Class 1: <21 kilograms of residual nitrogen per hectare (minimal)

Class 2: 21–40 kg N/ha (expected in areas of intensive agriculture with low-demand crops, such as cereals)

Class 3: 41–60 kg N/ha (expected in areas of intensive agriculture with high-demand crops, such as corn)

Class 4: >60 kg N/ha.

Farmland in classes 3 and 4 may be accumulating nitrogen and at risk of contributing nitrogen to surface water and groundwater.

Indicator results showed high levels of residual nitrogen (Class 4 in areas with high-demand crops and Class 3 in areas with low-demand crops) in the following areas: the lower Fraser Valley of British Columbia; the corridor of agricultural land from Lethbridge through Red Deer to Edmonton in Alberta; the Melfort area in northeastern Saskatchewan; the Red River Valley in Manitoba; southwestern Ontario, the area around Lake Simcoe, and the lower Ottawa Valley; the St. Lawrence Lowlands in Quebec and the region south of Quebec City; the Annapolis Valley in Nova Scotia; and the St. John River Valley in New Brunswick. There was a strong trend between 1981 and 1996 toward increasing levels of residual nitrogen in all provinces except British Columbia. The share of farmland showing an increase in residual nitrogen levels of at least 5 kilograms per hectare between these 2 years ranged from 27% in British Columbia to 80% in Manitoba.

Province	Farmland area* (million ha)	Share (%) of farmland in different classes of estimated residual nitrogen			
		Class 1 <21 kg/ha	Class 2 21–40 kg/ha	Class 3 41–60 kg/ha	Class 4 >60 kg/ha
British Columbia	1.5	70	19	3	9
Alberta	17.7	38	50	12	<1
Saskatchewan	23.0	31	61	8	<1
Manitoba	6.7	18	51	27	5
Ontario	4.2	26	22	15	37
Quebec	2.0	41	20	12	28
Atlantic provinces	0.5	52	33	12	4

* Farmland area here is the sum of all *Census of Agriculture* land classes except All Other Land.

Source: McRae et al., 2000



Eutrophication of an agricultural drain

Endocrine-disrupting chemicals

Endocrine-disrupting chemicals (EDCs) in the environment have recently emerged as a major international issue. Scientific studies in Canada and around the globe have shown that the growth, reproduction, and development of many species of invertebrates, fish, reptiles, birds, and mammals can be affected by chemicals that interact with endocrine systems.

The endocrine system is a complex mechanism that coordinates and regulates internal communication among specialized cells in various parts of an organism. Endocrine glands in fish, invertebrates, birds, and mammals secrete hormones, which act as chemical messengers that trigger biological functions such as growth, embryonic development, and reproduction. EDCs have the ability to alter, or disrupt, endocrine systems and thus affect these biological functions.

Known or suspected endocrine disruptors include industrial chemicals such as dioxin and PCBs; a number of now-banned pesticides, such as DDT and chlordane; and certain other synthetic chemicals, including some agents in pesticide formulations and chemicals in land-applied sewage sludge. Natural hormones, such as estrogens, are excreted in animal manures and may also be disruptive should they move to surface water and reach high concentrations.

The agriculture sector has been identified as a potential source of environmental EDCs through the use of pesticides and land-applied sewage sludge, and the production of natural EDCs in livestock wastes (e.g., sow and poultry manure). The International Joint Commission has noted that the high-volume use of pesticides, some of which are suspected EDCs, in the Great Lakes basin warrants further study. Research is currently being undertaken by Agriculture and Agri-Food Canada and by Environment Canada to determine if farming operations are a significant source of environmental EDCs and, if necessary, to develop mitigation technologies and best management practices that can be adopted by farmers.

E. Topp, Agriculture and Agri-Food Canada

tile drainage water or groundwater. Subsurface water containing nitrate moves through permeable underground zones, called aquifers, and may eventually reach surface waters. Aquifers are the source of drinking water in many parts of Canada (see Chapter 2). High concentrations of ammonia, another soluble form of nitrogen, can be toxic to fish. Runoff from stockpiled manure and inputs from sewage and industrial discharges sometimes contain elevated levels of ammonia.

Although nitrate itself is relatively nontoxic, it can be converted in the digestive tracts of human infants and ruminant animals (e.g., cattle and sheep) to nitrite, which is toxic. Nitrite causes *methemoglobinemia*, or blue baby syndrome, which impairs the blood's ability to transport oxygen. Most human cases of this condition related to drinking water have involved at least 40 milligrams of nitrate-nitrogen per litre. Nitrite has also been linked to the formation of nitrosamines that may cause cancer. Although surface waters rarely have concentrations of nitrate that exceed water quality guidelines, this is not the case with well water (see Chapter 6). High nitrate levels may also harm wildlife (see Chapter 7).

Phosphorus and nitrogen moving off farmland into surface waters typically do not reach levels that pose a direct risk to humans and animals. However, they may reach sufficient levels to cause *eutrophication* (see Chapter 7), a condition that sometimes occurs naturally but can be accelerated by human activity.

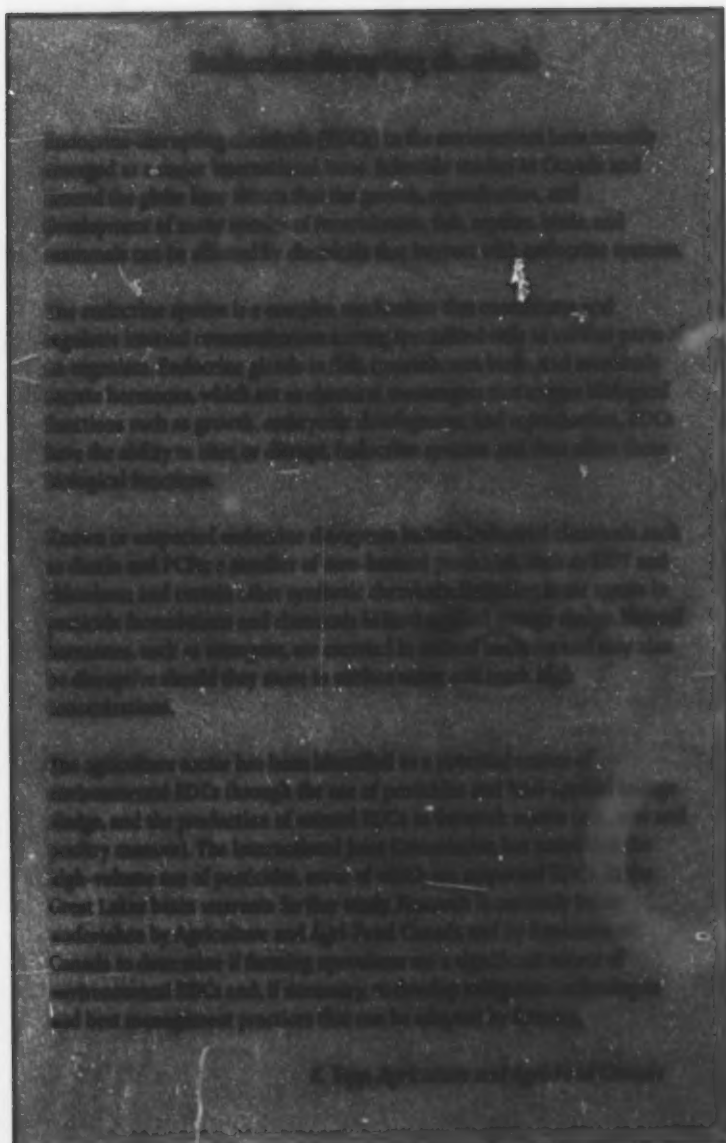
Pesticides

On farmland the presence of plants and animals is controlled to favour agricultural production. Thus, pesticides may be used to aid in controlling weeds, insects, other pests, and plant diseases that interfere with this production. By reducing the need for tillage to control weeds, herbicides offer the added benefits of reduced erosion and reduced fuel consumption with, consequently, less greenhouse gases produced. The following types of pesticides are commonly used in agriculture in Canada, in order of the quantity used:

- herbicides for controlling weeds
- insecticides for controlling insects
- fungicides for controlling fungal plant diseases.



Eutrophication of an agricultural drain



tile drainage water or groundwater. Subsurface water containing nitrate moves through permeable underground zones, called aquifers, and may eventually reach surface waters. Aquifers are the source of drinking water in many parts of Canada (see Chapter 2). High concentrations of ammonia, another soluble form of nitrogen, can be toxic to fish. Runoff from stockpiled manure and inputs from sewage and industrial discharges sometimes contain elevated levels of ammonia.

Although nitrate itself is relatively nontoxic, it can be converted in the digestive tracts of human infants and ruminant animals (e.g., cattle and sheep) to nitrite, which is toxic. Nitrite causes *methemoglobinemia*, or blue baby syndrome, which impairs the blood's ability to transport oxygen. Most human cases of this condition related to drinking water have involved at least 40 milligrams of nitrate-nitrogen per litre. Nitrite has also been linked to the formation of nitrosamines that may cause cancer. Although surface waters rarely have concentrations of nitrate that exceed water quality guidelines, this is not the case with well water (see Chapter 6). High nitrate levels may also harm wildlife (see Chapter 7).

Phosphorus and nitrogen moving off farmland into surface waters typically do not reach levels that pose a direct risk to humans and animals. However, they may reach sufficient levels to cause *eutrophication* (see Chapter 7), a condition that sometimes occurs naturally but can be accelerated by human activity.

Pesticides

On farmland the presence of plants and animals is controlled to favour agricultural production. Thus, pesticides may be used to aid in controlling weeds, insects, other pests, and plant diseases that interfere with this production. By reducing the need for tillage to control weeds, herbicides offer the added benefits of reduced erosion and reduced fuel consumption with, consequently, less greenhouse gases produced. The following types of pesticides are commonly used in agriculture in Canada, in order of the quantity used:

- herbicides for controlling weeds
- insecticides for controlling insects
- fungicides for controlling fungal plant diseases.

Until 1999 there existed no national database on the use of pesticides in Canada except for the broad-scale statistics collected through the *Census of Agriculture* and sales information collected by the Crop Protection Institute (an industry organization). Now a National Pesticides Sales Database is being prepared by Health Canada's Pest Management Regulatory Agency, supported by data from the Crop Protection Institute. Some provinces (e.g., Alberta, Ontario, and Quebec) also maintain databases on pesticide use. According to the census, the area of farmland receiving herbicides grew by 8% between 1991 and 1996, from 21.4 to 23.1 million hectares, or from about 52% to 56% of cultivated land (cropland plus summerfallow).

Many, but not all, pesticides are applied to soil. Some can vaporize from the soil or plant canopy, or be transported as aerosols through the air during spraying. Pesticides can wash off farmland in surface runoff and enter surface waters. They can also leach through the soil profile into tile drainage water or groundwater. The amount of pesticide lost from farmland, and how it is lost, is determined by the

- nature of the pesticide and the amount used
- weather conditions
- time elapsed between pesticide being applied and rainfall events
- physical and chemical properties of the soil
- slope of the field
- crop production practices.

In the past, pesticides were often highly toxic, persistent, or both, posing great concern for human and animal health. Today's pesticides are generally less toxic, more specific, and less persistent, but their presence in water is still a concern and safe limits are not always known. Adopting the principles and practices of *integrated pest management* may reduce the dependence on pesticides (see Chapter 8).

Pathogens and other factors

Pathogenic organisms, including bacteria, viruses, and parasites, occur naturally in water and soil. However, the presence of fecal coliform bacteria can indicate that drinking water has been contaminated by human or animal waste. Bacteria from farmland can migrate into groundwater or



Pesticide use

be carried in surface runoff into surface waters. High levels of bacteria in drinking water wells are sometimes traced to poor well construction or maintenance, as well as to point sources such as faulty septic fields or sewage disposal systems, large feedlots or exercise yards, and open manure piles.

Certain *heavy metals* (e.g., cadmium, mercury, and lead) are toxic to humans and wildlife. Heavy metals can enter agricultural soils as a result of atmospheric deposition or the application of municipal sewage sludge, industrial sludge, effluent for irrigation, mineral fertilizers, or animal manure. Sludge application is regulated in many parts of the country to prevent the buildup of heavy metals to unsafe levels. There is also concern that heavy metals held by agricultural soils may be released into groundwater and surface waters, posing a potential health risk to humans and aquatic life. However, research indicates that this is not a problem.

A developing concern for water quality is the potential for *endocrine-disrupting chemicals* to affect fish, wildlife, and humans using water that might be contaminated by agricultural or industrial runoff, or by long-range atmospheric deposition. Laboratory studies have established that the potential exists, but it is still uncertain if the issue is significant in Canadian waters, or if there is a problem related to agriculture or other rural water use (see Box opposite).

Water quality required for livestock

Physical and chemical attributes (e.g., pH, alkalinity, hardness, and salinity) do not usually constitute a major risk to animal health or safety as long as they are within the limits given in the table below. Concentrations of total dissolved solids greater than 3000 milligrams per litre negatively affect the health and performance of livestock, causing greater urine output and, in dairy cows, lower milk production. Taste, odour, and colour compounds can be detected by animals but generally do not have a direct effect on health and productivity. They can, however, indicate organic or inorganic contamination and should not be ignored.

Trace elements are chemical elements normally present in very small amounts in living organisms. Excess amounts of such elements (e.g., copper, zinc, manganese, selenium, and iron) may cause a nutrient imbalance in livestock feed and reduce the absorption of other minerals. Toxic substances may be found in water, either naturally or as a result of pollution from human activities. Common examples include arsenic, lead, mercury, hydrocarbons, and organochlorines.

The *Canadian Water Quality Guidelines for Livestock Water* provide guidelines for substances such as trace elements and toxic compounds. If levels exceed the guidelines, animals may experience problems with productivity and health. Cattle, for example, are very susceptible to nitrate poisoning, since they convert nitrate into nitrite in the rumen, inhibiting the transport of oxygen in the bloodstream. High nitrogen concentrations in water may cause pregnant cows to suffer from methemoglobinemia, which can result in the death of a newborn calf. Pigs can also be affected. High sulfate concentrations cause gastrointestinal inflammation and diarrhea in young calves and newly weaned pigs.

Micro-organisms such as viruses, bacteria, protozoa, and algae are often found in livestock drinking water and can lead to serious health problems or death. Diseases that can be contracted from these microbes include diarrheal diseases, black leg, botulism, brucellosis, tuberculosis, and foot rot. The presence of blue-green algae is a concern, as more than 50% of blooms contain either brain or liver toxins that can lead to reduced liver function or to sudden death.

**Limits for some physical and chemical parameters
of water for livestock drinking**

Parameter	Desirable range	Unacceptable values
pH	6.5–8.3	less than 5.5, more than 8.5
Total alkalinity	less than 400 mg/L calcium carbonate	more than 5000 mg/L calcium carbonate
Total hardness	less than 180 mg/L	not established
Total dissolved solids	less than 500 mg/L	more than 3000 mg/L
Sulfate	less than 1000 mg/L	more than 2500 mg/L

Source: Léonard and Leduc, 1997; Veenhuizen and Shruson, 1992

F. Croteau and D.I. Massé, Agriculture and Agri-Food Canada

Agriculture's need for good-quality water

Irrigation

Good-quality water is needed for irrigation to protect the health of the receiving crop, the soil, and the underlying groundwater. For example,

- pathogens in irrigation water can survive on the crop receiving the water
- herbicide residues present in small amounts in irrigation water may damage certain crops
- high salt content in irrigation water may make it difficult for certain plants to absorb sufficient water from the soil and could contribute over time to salt accumulating in soils or groundwater
- certain organic contaminants can discolour fresh vegetables, berries, and fruits, making them less desirable to the consumer.

Livestock

Standards for water quality vary among the types of livestock. Cattle are generally more tolerant of poor-quality water than poultry or swine, and adults are more tolerant than young animals. Environmental factors, such as temperature, can also affect the suitability of water for livestock drinking. Under heat stress, animals consume larger volumes of water and thus greater levels of water contaminants, which in turn may affect their health.

As is the case for human consumption, drinking water for livestock must meet certain guidelines (see Box opposite) that relate to

- physical and chemical attributes
- taste, odour, and colour
- substances present in excess amounts (trace elements)
- toxic compounds (nitrate, pesticides)
- micro-organisms (viruses, bacteria, protozoa, blue-green algae).

Water quality may also affect equipment used in the livestock industry. The quality requirements for equipment and sanitation may be higher than for consumption. For example, restricted-flow watering devices may become clogged by the buildup of minerals, sediment particles, or

organic growth. Acidic water can cause pipes to corrode. Water that is highly alkaline or high in calcium and magnesium can cause scale to build up in pipes and on other equipment.

Domestic use

Individual rural residents are largely responsible for ensuring that the water they drink is safe. This responsibility is made more difficult by a lack of appropriate, affordable treatment technology for small systems. In recent years, greater attention has been paid by provincial and federal governments and private industry to rural water quality issues. Under Canada's Green Plan, funding was made available during the early to mid-1990s for research and extension projects that helped to characterize the nature of these issues and develop appropriate technologies and management practices to improve water quality.

The quality of both surface water and groundwater sources can vary considerably throughout the year. It is desirable to treat and disinfect every water supply used for domestic purposes, based on regular water quality tests. Tests should include parameters such as coliforms, nitrate, total dissolved solids, and any others that may be of local concern, such as iron, manganese, sodium, sulfate, or arsenic.

Interprovincial and international issues

Water quality is not just a local concern.

Contaminants in surface and groundwater often travel long distances, crossing provincial and national borders (see Box, p. 63). Water quality is a major issue for the many transboundary waters that we share with the United States (see Box, p. 42), requiring Canadians to consider the rights and needs of downstream users.

Conclusion

It is difficult to assess trends in water quality across time and space in Canada because of limited data. However, many regional and local water quality studies have been carried out for various purposes by different groups. Findings

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The quality of transboundary waters

In places, the Canada-U.S. border follows or crosses rivers and watersheds. For example, the upper St. John River in New Brunswick, the St. Lawrence River, the Great Lakes, and several western rivers such as the Red River in Manitoba, the St. Mary and Milk rivers in Alberta, and the Flathead River in British Columbia all share or cross our common border. Activities on these rivers and watersheds have impacts that are felt on both sides of the border. Water quality concerns that may arise in these boundary waters are referred to as transboundary concerns.

Following disputes between Montana, Alberta, and Saskatchewan over the St. Mary and Milk rivers, the 1989 Boundary Waters Treaty established the International Joint Commission (IJC). The IJC is the organization through which the two countries share the management of boundary and transboundary waters. Among other things, the commission provides a forum for public participation, engages local governments, and undertakes joint research.

Factors affecting the quality of transboundary waters

- population growth and urbanization
- climate change
- economic expansion, energy demands, and increased waste generation
- intensification of agriculture

Concerns related to transboundary waters

- water supply and demand
- chemical use and release
- loss of aquatic habitat and biological diversity
- waste management

The management of transboundary water concerns has often involved an array of jurisdictional, agrarian, and conservation measures. For example, a branch of the Michaudville River watershed in Franklin County, Maine, flows into the St. John River in Canada. An environmental assessment and watershed protection plan has been prepared in Maine by the affected Soil and Water Conservation Service, which includes farmers and government agencies, and by Aboriginal groups. This plan for improving water quality recommends soil and water conservation measures for farms, forestry, and land settlement in the watershed.

Research on transboundary water utilization continues to respond to population increases. For example, the commission estimates that by 2025 consumption of Great Lakes water will increase to three to eight times the level in 1975. Demands for use of transboundary waters for irrigation will increase as well. With these greater demands will come growing concern over water quality and the effects of changing, runoff, and deposition on this quality.

*E.A. Kirkham, International Joint Commission
G.L. Fairchild, Eastern Canada Soil and Water Conservation Centre*

from these studies have been widely used to describe water quality in Chapter 5 (Surface Water Quality) and Chapter 6 (Groundwater Quality). In some cases, data were available to help establish broad trends in an area. For some areas, case studies are presented to show how water quality is being monitored and managed

locally, usually at a watershed level. Where appropriate, the results of specific field research are reported. Research results that relate water quality to the health of aquatic ecosystems are presented in Chapter 7 (Ecological Issues), and Chapter 8 (Protecting Water Quality) presents research that demonstrates how agricultural effects on water quality can be reduced.

5. Surface Water Quality

P.A. Chambers, A.-M. Anderson, C. Bernard, L.J. Gregorich, B. McConkey, P.H. Milburn, J. Painchaud, N.K. Patni, R.R. Simard, and L.J.P. van Vliet

Surface water quality is not a uniform part of the environment. It varies from one location to another, depending on the source of the water, the nature of the land use, the climate, and the degree of human activity. However, there are some common factors that affect water quality throughout the world. Contamination of surface water can occur from a variety of sources, including agricultural practices, industrial activities, and urban runoff. In some areas, such as the Great Lakes, water quality is monitored closely to protect public health and the environment. Improvements in land use practices, wastewater treatment, and water management are helping to reduce the contamination of surface water.

- Pesticides enter surface water in surface runoff from agricultural land and by atmospheric deposition. They are detected in surface waters, but rarely at levels that exceed guidelines for drinking water. Guidelines for irrigation and for the protection of aquatic life are sometimes exceeded.
- Bacteria are common in surface waters. Elevated numbers are found in runoff from manured fields, though abundance in surface waters has not been linked to livestock density.
- Heavy metal contamination of surface waters derives mainly from natural sources and has not been reliably linked to agricultural practice, including land application of sewage sludge.

Introduction

Surface water quality refers to the physical, chemical, and biological characteristics of lakes, rivers, and estuarine waters. Water quality changes with the seasons and between geographic areas, even when no pollution is present. The background chemistry of river and lake water is determined by the soil, geologic formations, terrain, and vegetation in the drainage basin. Superimposed on this baseline condition are the substances introduced by human activity. In particular, changes in land use and management practices affect the quantity and quality of runoff water and, in turn, the water budget, water chemistry, and biological communities of receiving waters.

No single measure constitutes good surface water quality. For example, pristine lakes and rivers with few aquatic plants or algae may be desirable for water sports, but the small amount of plant life may limit the growth of aquatic insects and fish. Also, what constitutes good water quality in prairie wetlands may be too enriched with nutrients for water in lakes of the Canadian Shield. Good water quality of lakes and rivers therefore differs geographically as a function of both the geologic terrain and how the water is used.

The quality of transboundary waters

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- climate change
- economic expansion, energy demands, and increased waste generation
- intensification of agriculture

Concerns related to transboundary waters

- water supply and demand
- chemical use and release
- loss of aquatic habitat and biological diversity
- waste management

The examination of transboundary water concerns has often involved an array of jurisdictions, agencies, and conservation measures. For example, a branch of the Meduxnekeag River watershed in Aroostook County, Maine, flows into the St. John River in Canada. An environmental assessment and watershed protection plan has been prepared in Maine by the affected Soil and Water Conservation districts, which include farmers and government agencies, and by Aboriginal groups. This plan for improving water quality recommends soil and water conservation measures for farms, forestry, and road maintenance in the watershed.

Pressure on transboundary water resources continues to mount as populations increase. For example, the commission estimates that by 2035 consumption of Great Lakes water will increase to three to eight times the level in 1975. Demands for use of transboundary waters for irrigation will increase as well. With these greater demands will come growing concern over water quality and the effects of discharge, runoff, and deposition on this quality.

B.A. Kirschner, International Joint Commission

G.L. Fairchild, Eastern Canada Soil and Water Conservation Centre

from these studies have been widely used to describe water quality in Chapter 5 (Surface Water Quality) and Chapter 6 (Groundwater Quality). In some cases, data were available to help establish broad trends in an area. For some areas, case studies are presented to show how water quality is being monitored and managed

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5. Surface Water Quality

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Highlights

- The amount of sediment entering surface water from farmland is lowest in the Prairies and highest in the potato-growing areas of the Atlantic provinces. The risk of water erosion and wind erosion dropped in most provinces between 1981 and 1996, leading to a decline in the amount of soil reaching surface waters.
- Nitrogen and phosphorus are seldom present at concentrations considered toxic for human or livestock drinking water supplies, or for aquatic life. However, they may impair water quality through the process of eutrophication. Concentrations of nutrients in surface water often exceed one or more water quality guidelines in intensively farmed areas such as southern Quebec, where large quantities of manure and fertilizer are used. Improvements in tillage practices, manure storage, and fertilizer use are reducing the problem.
- Pesticides enter surface water in surface runoff from agricultural land and by atmospheric deposition. They are detected in surface waters, but rarely at levels that exceed guidelines for drinking water. Guidelines for irrigation and for the protection of aquatic life are sometimes exceeded.
- Bacteria are common in surface waters. Elevated numbers are found in runoff from manured fields, though abundance in surface waters has not been linked to livestock density.
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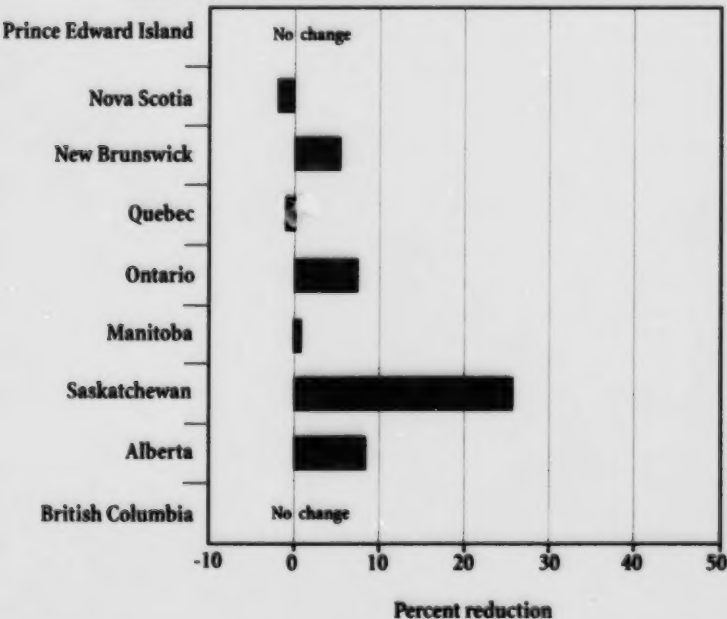
In this chapter, we examine the agricultural contribution to major physical, chemical, and biological factors of surface water quality. These factors include suspended sediments, nutrients, pesticides, pathogens, metals, and organic matter.

Suspended sediments

Much of the sediment in rivers comes from the river banks and river bed, but agricultural practices such as tillage and allowing livestock access to streams (see Box, p. 89) increase erosion and the movement of soil from farmland into neighbouring waters. In contrast, reservoirs reduce sediment loading to outflowing rivers. The *Canadian Water Quality Guidelines for the Protection of Aquatic Life* recommend that total suspended solids in an effluent during high flow conditions either

- be no more than 25 milligrams per litre above background levels for receiving waters that contain more than 25 milligrams per litre but less than 250 milligrams per litre, or
- should not increase the concentrations in receiving waters by more than 10% of background levels when these contain more than 250 milligrams per litre.

Figure 5-1
Changes in the area of
cropland at risk of
exceeding a tolerable level
of water erosion between
1981 and 1996



Source: McRae et al., 2000

During low, or clear, flow conditions, the guidelines limit any increase to 25 milligrams per litre for periods of less than 24 hours, and to 5 milligrams per litre for periods up to 30 days.

Soil is most susceptible to water erosion during the spring snowmelt, when a large proportion of the annual loss of soil occurs (see Black Brook case study). The loss from the field also depends on the size of the soil particles. Sand settles faster than fine clay particles, so sediments reaching water bodies will often be enriched in organic and fine-textured fractions compared with the soil from which they came (Table 5-1). This process enriches the nutrient content of the sediments, because these fractions typically bind more nutrients than coarse sediments do.

Table 5-1
Enrichment of eroded sediments compared
with two uneroded Quebec soils from which
they were derived

Soil and sediment component	Silt loam (% change)	Gravelly loam (% change)
Clay	40	80
Sand	-60	-60
Organic matter	10	110
Available phosphorus	98	150
Available potassium	290	80

Source: Bernard et al., 1992

Between 1981 and 1996, the risk of water erosion fell in Alberta, Saskatchewan, Manitoba, Ontario, and New Brunswick. The risk remained the same in British Columbia and Prince Edward Island and rose in Quebec and Nova Scotia (Fig. 5-1). Reduced erosion may result in less sediment in streams, depending on the extent to which surface runoff carries sediments from the field to stream. Local soil, slope, and vegetation combine to determine this rate of delivery. Soil erosion by water is generally less severe in the drier regions of Canada, such as the interior of British Columbia and the Prairies, because they receive less precipitation.

The following regional descriptions give sediment values when these are available and also refer to Agriculture and Agri-Food Canada's agri-

Case study

Black Brook experimental watershed, New Brunswick

The Black Brook watershed covers about 1450 hectares north of Grand Falls, N.B., 65% of which is rolling farmland. The major crop is potatoes rotated with grain, peas, and hay, with some land kept in pasture. The Black Brook experimental watershed was established in 1991 to evaluate the effect of intensive potato production on sediment yield and chemical loading of surface water.

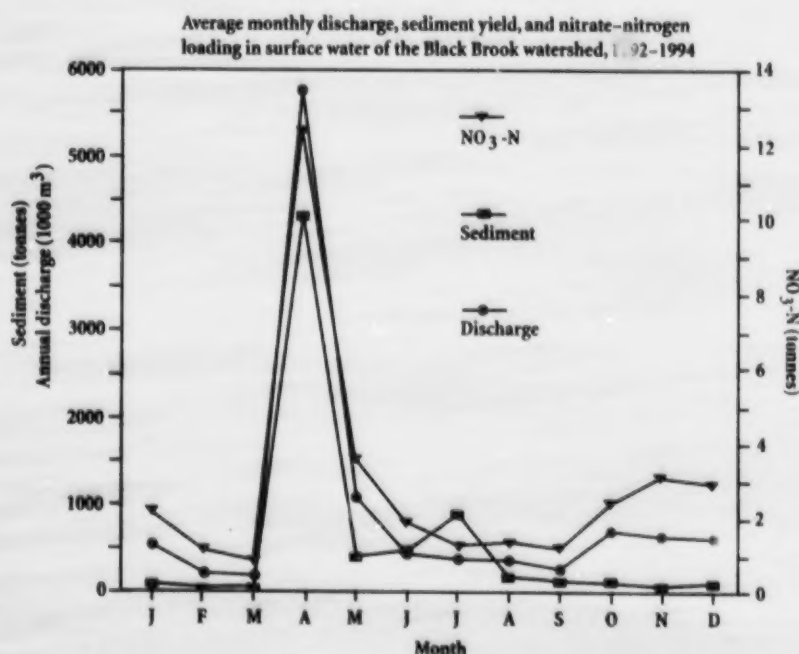
Climate is monitored at five weather stations in the watershed. Water quality is monitored at permanent gauging stations in eight subwatersheds, five winterized weirs, and five multi-level groundwater monitoring wells.

From 1992 to 1994, records show the following:

- Annual discharge averaged 10.9 million cubic metres, 53% of which occurred during spring runoff in April.
- Annual sediment yield averaged more than 6500 tonnes (4.5 tonnes per hectare), 65% of which was discharged in April; 28% was discharged in May to August.
- Annual chemical loadings in soluble form were about 6, 1, and 17% of the annual fertilizer inputs for nitrate-nitrogen, phosphate, and potassium, respectively.

Suspended sediment concentration during 1992 to 1994 exceeded 10 milligrams per litre for several months. Several summer rainfall events produced concentrations greater than 20 000 milligrams per litre. Nitrate-nitrogen concentrations exceeded the Canadian water quality guideline for drinking water (10 milligrams per litre) only twice, but they consistently ranged from 2 to 9 milligrams per litre, well above background levels of less than 1 milligram per litre. Nitrate levels rose after fertilizer was applied. Phosphate concentrations were generally less than 100 micrograms per litre, though several events resulted in concentrations exceeding 200 micrograms per litre.

Herbicides, insecticides, and fungicides are used extensively in the watershed. Analysis of 54 samples collected from November 1993 to January 1995 showed that three pesticides (chlorothalonil, pirimicarb, and metribuzin) were occasionally detected at low levels. In contrast, on three dates carbofuran was present in concentrations of more than 1 milligram per litre. Most measurable concentrations of these four pesticides coincided with application on growing crops.



T.L. Chow, P.H. Milburn, and H.W. Rees,
Agriculture and Agri Food Canada

Case study

South Tobacco Creek, Manitoba

The South Tobacco Creek Pilot Project, launched in 1991 under the Canada-Manitoba Agreement on Soil Conservation (CMASC), is a cooperative investigation of the impacts of agriculture on land and water ecosystems within the South Tobacco Creek basin in southern Manitoba. The project is a joint effort of 42 local farmers, the Deerwood Soil and Water Management Association, University of Manitoba, federal and provincial governments, and privately owned industry, and is now funded by other government programs and private industry.

The overall project has involved a hydrological study and collection of data on runoff from four small watersheds; continuous and daily rainfall; and land use and management practices, including applying fertilizer, herbicides, and insecticides, tillage, and cropping. Research initiatives include

- a study called Twin Watersheds that involves collecting runoff data and water samples to assess the hydrological, sediment, and nutrient characteristics of runoff from two small adjacent watersheds. One is farmed using no-till and the other is tilled conventionally. The objective is to integrate information on land use, farming practice, runoff, and nutrients into a watershed model that can be used to assess the impacts of agriculture on land and water ecosystems.
- tracking the movement of agricultural pesticides within the watershed to determine the sources and pathways of pesticides found in runoff water and to assess the relative importance of atmospheric sources.
- a recent (1998) initiative to study hog manure application. Liquid hog manure is applied to farmland in a small basin and then tilled into the soil. Surface runoff is being analyzed for nutrients and bacteria.
- a study to evaluate the impact of small headwater storage dams on sediment and nutrients. Water samples are taken above and below two dams used to monitor runoff.

Water quality measurements for South Tobacco Creek ranged during the course of the multi-year study from 6.8 to 43 milligrams per litre (mg/L) for total organic carbon, 0.3 to 4.3 mg/L for total nitrogen, and 0.05 to 2.9 mg/L for total phosphorus. Lower values for these parameters were observed during periods of reduced flow. Sediment levels from the upland watershed, including channel erosion, were relatively high, with about 435 kilograms per hectare leaving the watershed annually.

Seven pesticides, two not used in the basin, have been detected in stream water at levels well below Canadian water quality guidelines for aquatic life. Concentrations of four herbicides (2,4-D, dichlorprop, MCPA, and bromoxynil) in South Tobacco Creek ranged from less than 0.01 nanograms per litre (ng/L) to a maximum concentration of 680 ng/L (for 2,4-D) and reflected local application times. Discharge of these herbicides into South Tobacco Creek was calculated to be less than 0.01% of the quantities used in the watershed. Herbicide concentrations were not related to runoff losses, instead corresponding to elevated levels in precipitation and air measured in the watershed. Spring melt concentrations were important when no significant runoff events occurred late in the previous growing season.

An integral part of the South Tobacco Creek Pilot Project has been educational extension and building awareness. Project findings are presented on a web site (<http://www.deerwood.mb.ca>) and in related brochures. An educational component targeted at schools is designed to convey to children an understanding of the relationship of agriculture to the environment.

J. Yarotski, Agriculture and Agri-Food Canada

environmental indicator estimates of the risk of soil erosion by water and wind.

British Columbia

In British Columbia (1981–1996) about 6% of cropland shifted to the moderate risk class for water erosion, mainly from the low risk class. Although the share of cropland at tolerable risk of water erosion remained constant between 1981 and 1996, there were areas in the south and central regions of the province where the risk increased slightly, despite improvements in farming practice and the use of conservation tillage.

In a 1994 study of the Sumas River watershed, average values for total suspended solids ranged from 19 to 66 milligrams per litre of water at nine sites. The concentration of suspended solids was generally higher on rainy days (9 to 95 milligrams per litre) than on clear days (10 to 23 milligrams per litre).

Prairie Provinces

The potential for soil erosion by water in the Prairies and for sediment entering streams is limited by the dry climate and pothole topography, with its many closed basins (i.e., no outlet to a major river). All three Prairie provinces showed a reduction in the estimated risk of water erosion between 1981 and 1996 (see Fig. 5-1), largely from making changes in cropping systems (mainly less area under summerfallow and more area under forages) and adopting *conservation tillage* and *no-till* practices. Manitoba showed the least reduction in risk, because 88% of cropland in this province was already at tolerable risk of erosion in 1981. Sediment loss from cultivated land during the spring melt is typically less than 1 tonne per hectare, although it can reach 10 tonnes per hectare. This sediment is transported to small streams, and then can be carried into larger water bodies during subsequent major runoff events. Total sediments leaving the South Tobacco Creek watershed in Manitoba were measured at an average of 435 kilograms per hectare per year, including channel and streambank erosion (see Case study opposite).

Related to wind erosion, one of the greatest concerns for water quality exists where ditches, water channels, or small water bodies are located immediately downwind of a severely eroding field



Wind-blown soil in a Saskatchewan roadside ditch

and can be filled by wind-blown soil. Between 1981 and 1996, the share of cultivated land in the Prairies at high to severe risk of wind erosion dropped from 15% (5 million hectares) to 6% (2 million hectares).

Central Canada

Soil erosion and sedimentation of streams have long been a problem in Ontario. Factors that contribute to a high level of erosion and delivery of eroded soil into streams include

- much land planted in wide-row crops, such as soybeans and corn
- intense summer storms
- extensively developed networks of farm ditches and municipal drains.

Measurements of sediment in streams of the region are few. Those that do exist are difficult to interpret, because sediment concentrations vary more with stream flow than do concentrations of dissolved chemicals. Measurements made in the mid-1970s in the Ontario portion of the Great Lakes basin showed that average sediment concentrations were about 50 milligrams per litre in clay watersheds and about 30 milligrams per litre in sandy watersheds. Sediment concentrations of up to 400 milligrams per litre occurred during periods of maximum flow in sandy as well as in clay soil watersheds.

Expressed in another way, a yearly average of 300 kilograms of sediment for each hectare of agricultural land was carried in streams draining that land. Values ranged from less than 50 to almost 1000 kilograms per hectare per year, depending on the soil type (clay soils giving the highest sediment loads) and the intensity of row cropping. On average, 14% of the sediment loads came from stream bank erosion, some of which was natural.



Soil erosion by water during spring melt

The seriousness of the problem seems to have peaked in the early 1980s, a time of unprecedented expansion of intensive row cropping in Ontario. At that time, continuous monoculture was favoured over rotations of wide-row crops with hay or narrow-row crops, such as oats and wheat.

Between 1981 and 1996, the risk of soil erosion by water fell by an estimated 13% in Ontario (see Fig. 5-1). Reducing the amount of sediment in Ontario streams lowers the phosphorus concentrations in the water.

Quebec has a generally low overall estimated risk of soil erosion by water, with 88% of cropland in the tolerable risk class in 1996. However, in some areas the benefits of adopting conservation practices were offset by the intensified production of row crops (e.g., soybeans, grain and silage corn, and vegetables) and a concurrent reduction in the area under crops that provide better protection against erosion (e.g., alfalfa and spring cereals), causing a slight overall increase in the risk of water erosion in the province between 1981 and 1996 (see Fig. 5-1). Still, Quebec is unique among the provinces in having no cropland in the high and severe risk classes.

Measurements of erosion at the field scale in Quebec showed that about 30 to 70% of eroded

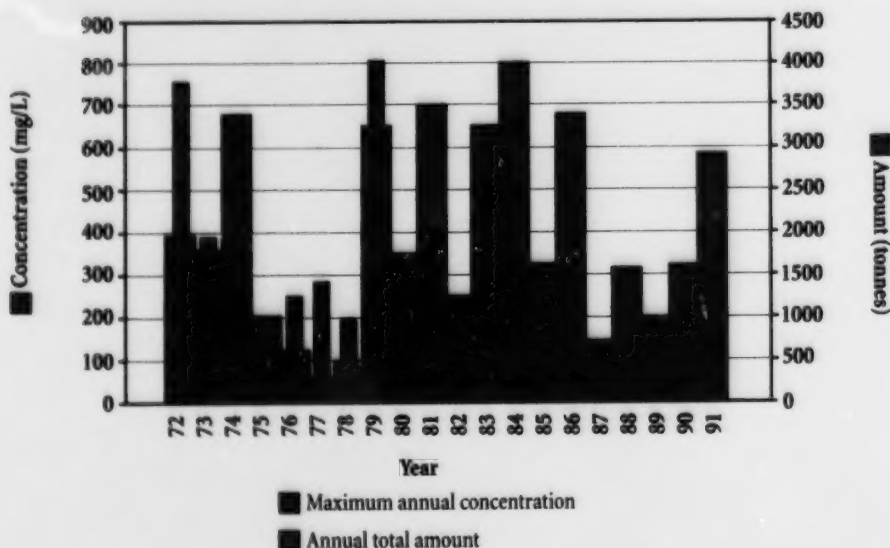
soil moves off the field. The lower values were measured on a dairy farm with extensive hay production and the higher values, where vegetables were produced.

Atlantic Provinces

Potato-growing areas in New Brunswick and Prince Edward Island are particularly vulnerable to water erosion and sedimentation of water courses, especially in rolling landscapes where potatoes are planted up and down the hills rather than across slopes. Soil losses of up to 40 tonnes per hectare per year have been measured under these conditions, whereas losses of 5 to 6 tonnes per hectare per year were measured where potatoes were planted across the slope. Between 1981 and 1996, the risk of soil erosion by water declined in New Brunswick, mainly because its share of cropland at high risk was halved during this period. The water erosion risk stayed constant in Prince Edward Island during this period but rose slightly in Nova Scotia (see Fig. 5-1), probably because of the large areas under vegetables and berries.

Sediment concentrations in streams in intensively farmed areas of Atlantic Canada are often high (Fig. 5-2). Concentrations of 5000 milligrams per litre are not uncommon at some sites during or immediately after major rainfall events.

Figure 5-2
Suspended sediments in
the Wilmot River, P.E.I.



Source: Government of Prince Edward Island, 2000

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Nutrients

Nitrogen and phosphorus are essential in moderate amounts to have a healthy lake or river that supports plants, aquatic insects, and fish.

Under natural conditions, these and other nutrients reach surface waters

- in surface runoff from undeveloped land
- in precipitation and dust falling directly on the water's surface
- in groundwater inputs and tributary inflows
- from bottom sediments of lakes or rivers
- as decaying plant or animal material
- by fixation (of nitrogen only) from the atmosphere by certain algae.

Nitrogen and phosphorus occur in several forms (see Box). Only dissolved forms can be taken up by plants. Many human activities accelerate the addition of nutrients to surface waters. Human sources of nutrients include

- sewage and stormwater discharges, including losses from septic field systems (see Box, p. 50)
- industrial wastewater
- agricultural sources, such as fertilizer, manure, and sewage sludge (biosolids), applied to fields or leaked from storage containers.

Regional data on nutrient levels in surface waters follow. Estimates of the level of residual nitrogen (nitrogen remaining in the soil after harvest; see Box, p. 37) and the risk of water contamination by agriculturally derived nitrogen and phosphorus (calculated as part of Agriculture and Agri-Food Canada's recently reported Agri-Environmental Indicator Project) are also discussed when they apply. The risk values are restricted to British Columbia, Central Canada, and the Maritimes for the indicator of nitrogen contamination (Table 5-2), and to Quebec for the indicator of phosphorus contamination. In both cases, the risk was calculated mathematically using various estimates of climate, topography, soils, and land management practices. These risk indicators are useful in showing general trends in the amount that agriculture contributes to water contamination but may not reflect field conditions accurately for specific locations.

Forms of nutrients entering surface waters
Phosphorus and nitrogen reach surface waters in different forms. These forms vary in their availability to aquatic vegetation.

Form	Common sources	Availability to aquatic vegetation
Particulate inorganic phosphorus	Bound to sediment particles	Variable (ranging from few % to >75% available)
Soluble inorganic phosphorus	Decomposing manure, plant residues, fertilizer, sewage, industrial wastewater	Readily available
Organic phosphorus	Soils, plant residues, manure, sewage	Becomes available when organic matter decomposes
Organic nitrogen	Soils, plant residues, manure, sewage	Becomes available when organic matter decomposes
Inorganic nitrogen as nitrate or ammonium	Soils; surface-applied fertilizers; decomposed manure, plant residues, sewage, industrial wastewater	Readily available

R.A. Chambers, Environment Canada

Table 5-2
Risk of contamination by nitrogen on farmland in Canada's humid regions under 1996 management practices

Province	Farmland area * (million ha)	Share of farmland in various estimated water contamination risk classes (%)		
		Low (0–6 mg N/L)	Intermediate (6.1–14 mg N/L)	High (>14 mg N/L)
British Columbia	0.1	6	25	69
Ontario	4.2	39	44	17
Quebec	1.9	58	35	6
Atlantic provinces	0.4	82	15	3

* Farmland area is the sum of all *Census of Agriculture* land classes except All Other Land. Not all farmland analyzed.

Source: McRae et al., 2000

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Impact of rural septic field systems on surface water

Septic tanks with tile fields or mounds are widely used as disposal systems for sewage from rural homes and farm wastewater. Septic field systems may or may not be effective in preventing nutrients and pathogens from entering shallow groundwater. Impacts on surface water in turn depend on the characteristics of the water body receiving that groundwater. The amount of nutrient loading to water bodies from a septic field system depends on

- quantity of sewage
- efficiency of retention in the septic field (depending on soil type and geology)
- rate (and distance) of transport of materials between the septic system and the water body.

Wastewater from poorly maintained systems can also reach streams and lakes through overland flow.

The degree to which nutrients are retained in a septic field depends on the age of the field and soil characteristics. In general, fine-grained soils with high clay content are more effective in retaining phosphorus than sandy soils or soils with a lot of gravel. Soil chemical characteristics are also important. Phosphorus binds tightly to soils containing high levels of iron and aluminum in neutral to acidic soils, or high levels of calcium in neutral to alkaline soils. As a rule, average septic field systems will retain about 20 to 55% of nitrogen, and 25 to 40% of phosphorus. Properly designed septic tile filter beds can retain a far greater amount of nutrients (up to 88% in one study). However, an average of 61% of the septic fields checked in several surveys of cottage systems in Ontario were not properly designed, constructed, or maintained.

Few studies have examined the impact of septic field systems on running water, but the impact of nutrient loading from septic field systems near lakes has been investigated in various studies. In one U.S. study, on-site septic systems supplied 1 to 33% of the total phosphorus budget of three lakes, but this contribution was not thought to have a significant impact on overall algal productivity. In a study of Pine Lake in Alberta, phosphorus from sewage was thought to comprise at most 6% of the total phosphorus budget. However, sewage accounted for 67% of the total phosphorus supplied to Jackfish Lake, near Edmonton, because of its small watershed, many cottages, and little internal loading. Streams and lakes in small watersheds are most likely to be affected by poorly designed and maintained systems.

A.J. Sosiak, Alberta Environment

British Columbia

In British Columbia, the impact of agricultural activities on water quality is most obvious in the intensively farmed area of the Lower Fraser Valley, where there are high animal densities and an insufficient land base to fully use the manure produced (see Box, p. 63). The nitrogen budget calculated for this area indicates a net surplus of

4700 tonnes of nitrogen per year, or about 70 kilograms of nitrogen per hectare of land in agricultural production.

As well as moving into groundwater (see Chapter 6), a large share of this nitrogen is lost from fields by runoff to surface water. Great potential exists, however, to reduce nitrogen losses to surface water through improved on-farm manure and nutrient management strategies (see Chapter 8).

Winter sampling was carried out at several sites in the Sumas River watershed in 1994. Nitrate-nitrogen concentrations ranged from 2 to 5 milligrams per litre of water (below the Canadian drinking water guideline of 10 milligrams per litre). At the time of this study, 70% of farmland in this watershed was occupied by dairy farmers and 17% by produce farms and nurseries; 84% of the former and all of the latter used commercial fertilizer.

In the same study, total phosphorus concentrations at nine sites ranged from 0.043 to 0.265 milligram per litre of water. No Canadian or provincial guidelines exist for phosphorus in stream water. The dissolved oxygen concentration at several sites was lower in the fall than the Canadian guideline for aquatic life. Recommendations for remedial action involved tracing depressed oxygen levels to their cause.

Overall, residual nitrogen levels dropped by more than 5 kilograms per hectare on more than 50% of British Columbia's farmland area between 1981 and 1996. Still, the estimated risk of water being contaminated from agricultural activities is high for 69% of farmland in the humid region of this province (representing about 5% of British Columbia's farmland) (see Table 5-2).

Prairie Provinces

In the Prairies, the dry climate makes ponds and small lakes particularly prone to excessive concentrations of phosphorus and, to a lesser extent, nitrogen. Analysis of lake sediments indicates that some prairie lakes were eutrophic before European settlement because of the naturally nutrient-rich soils, long residence times, and high evaporation rates.

A recent study of surface water quality in Alberta found that nitrogen and phosphorus often

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Table 5-3
Aspects of water quality of some Alberta surface waters

Water body	Intensity of farming	Nutrient	No. of samples	Share that exceeded provincial guidelines for aquatic life * (%)
Streams				
(1995–1996)	High	Total nitrogen	214	87
		Total phosphorus	220	99
		Ammonia	70	0
	Moderate	Total nitrogen	343	65
		Total phosphorus	341	88
		Ammonia	126	0
	Low	Total nitrogen	163	32
		Total phosphorus	164	89
		Ammonia	162	0
Lakes (1995–1996)	High	Total phosphorus	69	96
	Low	Total phosphorus	23	38
Irrigation canals				
(1977–1996)				
Supply source		Total phosphorus	183	16
Return flow			1034	61

* The limits for aquatic life are the Alberta Environment Protection guidelines of 1 mg/L total nitrogen, 0.05 mg/L total phosphorus, and the Canadian Water Quality Guidelines for the Protection of Aquatic Life maximum acceptable concentration of 1.13–1.81 mg/L ammonia–nitrogen (depending on temperature and pH).

Source: CAESA, 1998

exceeded interim provincial guidelines (the Canadian guidelines do not include total nitrogen or any form of phosphorus) for protecting aquatic life in streams, lakes, and irrigation canals, even in areas of low-intensity farming (Table 5-3). In a small, intensively cultivated sub-basin of one Alberta stream, nitrogen and phosphorus in runoff over 2 years amounted to about 13% of the nitrogen and about 4% of the phosphorus applied as fertilizer. In another study of small agricultural watersheds in Manitoba, nitrogen never exceeded Canadian guideline levels (see South Tobacco Creek case study, p. 46).

In a recent Saskatchewan study, nitrate concentrations in snowmelt runoff from fields under summerfallow consistently exceeded concentrations in runoff from cropped fields. Nitrate concentrations in runoff were usually within guidelines for drinking water, although at

one site, in a year when runoff volumes were low, nitrate concentrations in snowmelt runoff from summerfallow exceeded Canadian guidelines for drinking water quality.

Besides being eutrophic, many prairie lakes have blooms of toxic algae. Livestock, wildlife, and pet poisonings from ingesting cyanobacterial toxins in water supplies are reported occasionally. Reports of such poisoning were received before the use of inorganic fertilizers began and intensive livestock operations were established. It is still not known how additional nutrients from agriculture and other sources affect these algae.

Indicator values for the level of residual nitrogen show that Alberta has 88% of farmland in the lowest two classes (less than 40 kilograms of nitrogen per hectare); Saskatchewan, 92%; and Manitoba, 69% (see Box, p. 37). These relatively low levels of soil nitrogen and the semi-arid

conditions in much of the Prairies combine to keep the risk of water contamination by nitrogen generally low in this region. However, the indicators are not sensitive enough to make assessments for specific areas, such as intensive livestock operations, which are known to raise the risk of water being contaminated locally.

Central Canada

A recent survey in southwestern Ontario found that nitrate levels were rising in a watershed undergoing more intensified cultivation and increased rural residential population (see Case studies on surface water quality in rural Ontario). In contrast, phosphorus levels seemed to be falling, probably because of the growing use of conservation tillage, which reduces soil erosion and the associated movement of phosphorus.

Surveys of rivers in agricultural basins of southwestern Quebec from 1979 to 1994 showed that most had total phosphorus concentrations above the provincial guideline of 0.03 milligram per litre and that agriculture was a major cause. Data analysis over the time of the study indicated that nitrate concentrations were increasing. A survey of the Yamaska River showed that 16% of the ammonium-nitrogen samples exceeded the guideline of 0.5 milligrams per litre (see Yamaska River case study, p. 54). Ammonium concentrations were typically higher following application of manure, nitrogen fertilizer, or both. Recent improvements in manure storage and reduced and better use of mineral fertilizer have resulted in lower ammonium concentrations.

In 1996, Ontario had 37% of farmland in the highest class of residual nitrogen (more than 60 kilograms of nitrogen per hectare), for which the environmental risk is high; Quebec had 28% of farmland in this class. Levels of residual soil nitrogen rose by at least 5 kilograms per hectare over much Ontario (69%) and Quebec (71%) farmland between 1981 and 1996, reflecting the growing intensity of agricultural production.

In Quebec in 1996, 19% of agricultural land was at low risk of causing water contamination by agriculturally derived phosphorus, 73% at medium risk, and 8% at high risk (Fig. 5-3). Most of the areas estimated to cause medium or higher risk were located in the St. Lawrence Lowlands and the region south of Quebec City, where agriculture is most intensive.

Atlantic Provinces

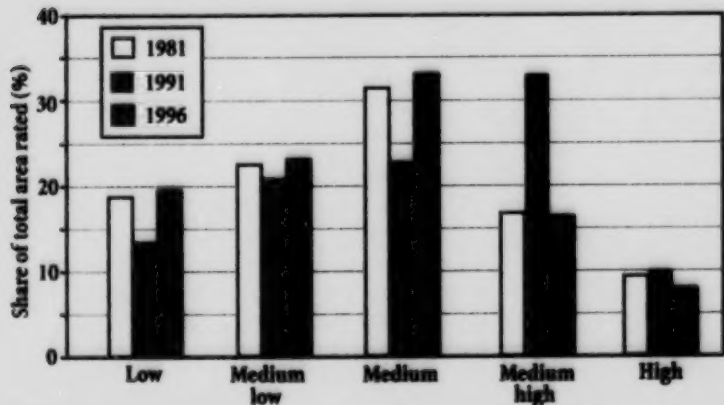
In the late 1980s, 95 surface waters in Atlantic Canada that were sources of municipal drinking water were sampled for nitrates. Of these, 25% were located in areas of moderate to high agricultural intensity. Nitrate-nitrogen never exceeded 1 milligram per litre, substantially less than the Canadian guideline of 10 milligrams per litre for drinking water.

Nitrate was found in higher concentrations in surface water in small watersheds with intensive agriculture, such as Black Brook in New Brunswick, where potatoes are the major crop (see Black Brook case study, p. 45). As well, nitrate concentrations in the range of 1 to 25 milligrams per litre have been detected for short periods in waters discharging from tile drainage systems commonly found beneath farm fields in Atlantic Canada. These discharges are normally diluted by the receiving stream. In the Atlantic provinces, more than 80% of farmland was at low risk of water contamination by nitrogen in 1996 (see Table 5-2). However, the estimated nitrogen content of water increased by at least 1 milligram per litre of water on about 60% of farmland between 1981 and 1996.

Pesticides

Surface runoff from agricultural lands is an important pathway for introducing pesticides to surface waters. Recent studies have shown that

Figure 5-3
Changes in the risk of water contamination by phosphorus on Quebec's farmland between 1981 and 1996



Source: McRae et al., 2000

Case studies

Surface water quality in rural Ontario

Activities in several rural watersheds in southern Ontario over the last few years help to show some trends in surface water quality. One study, reported in 1999, compared water quality data over the previous 25 years in Huron County, a largely agricultural region bordering on Lake Huron. It was found that

- total phosphorus concentrations were falling at seven out of nine provincial water quality monitoring stations
- nitrate concentrations were rising at six of these stations
- fecal coliform bacteria counts were increasing at four of these stations
- the three river basins with the highest human populations consistently had the highest concentrations of these three water quality indicators
- the five river basins with the highest phosphorus and nitrate concentrations and highest fecal coliform counts had the greatest proportions of poorly and imperfectly drained soils
- four of these five basins had the greatest increase in improved farmland, indicating increased intensity of farming
- there was no relationship between livestock densities and water quality.



Another study conducted between 1993 and 1997 compared two small agricultural drainage sub-basins within the Kintore Creek watershed in Oxford County in the heart of southern Ontario's prime farmland. Soil conservation practices have been adopted extensively over the last 10 years in one of these sub-basins. Results showed that

- concentrations of total phosphorus were reduced in the conservation sub-basin during winter thaws, spring snowmelt, and severe rainfall events, when soil erosion and suspended sediments are usually highest
- suspended sediment concentrations were lower in the conservation sub-basin during 28 out of 38 severe storms that were sampled
- there was no detectable improvement in nitrate concentrations in the conservation sub-basin
- benthic (bottom-dwelling invertebrates) communities sampled from the conservation sub-basin were more consistent with undisturbed streams when compared with the control sub-basin
- atrazine concentrations collected from continuous samplers ranged from an average of 0.18 microgram per litre during base flow conditions to a maximum of 90 micrograms per litre during a storm event
- water quality during base flow was no different between the two sub-basins.

Although these results are not exhaustive, they show that adopting soil conservation practices reduces sediment concentrations and associated phosphorus in rural streams. They also show that nitrate and bacteria levels in rural Ontario streams are not improving, and may be affected by growing human populations.

*D. Joy and S. Bonte-Gelok, University of Guelph
C. Merkley, Upper Thames River Conservation Authority*

Case study

Yamaska River, Quebec

The Yamaska River, a tributary on the south shore of the St. Lawrence River, discharges into Lac Saint-Pierre between Trois-Rivières and Montreal. Its drainage basin, covering 4784 square kilometres, is the site of almost one-quarter of Quebec's agriculture.

Over the last 20 years, the basin's cultivated area has remained stable at about 210 000 hectares, or 43% of the total area. However, the agricultural activities of the Yamaska basin have changed a great deal. For example:

- Livestock numbers have increased by more than 30% (from 233 000 in 1976 to almost 311 000 in 1996), with livestock density increasing from 1.1 to 1.5 animals per cultivated hectare.
- Hog production has been particularly developed, with the number of animals increasing by nearly 100 000 for a total in 1996 of about 168 000, representing 54% of livestock production in the basin.
- The area of cultivated land occupied by wide-row crops, including corn, soybeans, and vegetables, rose from 22% in 1976 to 58% in 1996 (wide-row crops require a lot more fertilizer and pesticides than pasture and forages and are much more susceptible to water erosion because of the lack of plant cover between the rows).
- The area in forages and pasture dropped from 57% of the cultivated land in 1976 to 32% in 1996.

Hogs and corn are now the two most important commodities in the basin.

Water quality continues to be poor throughout the watershed, despite improvements since the late 1970s resulting from the clean-up efforts by the urban, industrial, and agricultural sectors. Phosphorus values exceed the Quebec guideline for the prevention of eutrophication (0.03 milligram of phosphorus per litre of water) almost everywhere in the basin. At the mouth of the river, median concentrations for total phosphorus (0.195 mg/L) and nitrogen (2.15 mg/L) are higher than in any other tributary of the St. Lawrence River. Although most water quality variables show downward trends between 1979 and 1997, the levels of phosphorus, nitrogen, chlorophyll-a (an index of eutrophication), suspended solids, and turbidity are still among the highest in Quebec. Observations in the Yamaska basin suggest a close relationship between agricultural pressures, which have reached an exceptional level for Quebec, and the quality of the water.

Agricultural activities are the principal sources of nutrients in the basin. Mineral fertilizers in particular are a source of 13 000 tonnes of nitrogen and 3800 tonnes of phosphorus applied to land in the basin. Agricultural sources contribute an estimated 70% of the nitrogen and 75% of the phosphorus carried by the Yamaska River into the St. Lawrence River. Agricultural land in the basin also receives substantial amounts of pesticides—the average pesticide application in the basin is 1.8 kilograms of active ingredients per hectare compared with the provincial average of 1.3 kg/ha.

Between 1992 and 1998, atrazine concentrations in the Chibouet River, a tributary of the Yamaska, exceeded guidelines for the protection of aquatic life in 16 to 50% of the samples. About 17 different pesticides and their degradation products are detected each year in this river. During summer 1998, atrazine, DEA, metolachlor, and bentazon were detected in 100% of the samples, and DIA, dimethenamide, dicamba, and 2,4-D were detected in more than 75% of the samples. On occasion, water quality guidelines are exceeded for metolachlor, cyanazine, metribuzin, MCPA, MCPB, and dimethenamide. Even when they are detected in low concentrations, the presence of several pesticides raises concerns because of the possibility of still-unknown additive or synergistic effects on aquatic life.

Measures taken to improve the quality of the water in the Yamaska River include

- a construction program, in effect since 1988, to build manure storage facilities
- regulation of manure spreading
- efforts to better use the agronomic potential of manure (e.g., an agency has been established to manage organic fertilizer, including better distribution and utilization)
- efforts to reduce the use of pesticides and promote integrated pest and weed management
- promotion of conservation tillage; chiseling, ridge tillage, and no-till are now used on 20% of the crop area.

Further improvement in the quality of Yamaska waters depends on continued promotion and adoption of good agricultural practices, particularly that of reducing the use of mineral fertilizers.

J. Painchaud, Ministère de l'Environnement du Québec

organic chemicals, such as the older organochlorine insecticides, may also enter surface waters by long-range transboundary atmospheric transport (see Box, p. 56). Much less is known about atmospheric deposition of the current generation of pesticides. Pesticide concentrations in surface waters vary considerably both regionally and across Canada.

British Columbia

A 1995–1996 comparison was made of pesticide loss in runoff from two manure treatments on silage corn in south coastal British Columbia. Plots on which manure was applied in the fall to a winter cover crop lost 6 grams of atrazine per hectare in runoff. In contrast, plots managed more conventionally (manure was applied in the fall and left exposed on the soil surface without a cover crop) lost 10 grams of atrazine per hectare in runoff. There was no difference in metolachlor losses (5 grams per hectare). Mean concentrations of atrazine under conventional management exceeded Canadian guidelines for aquatic life, but under winter cover crop management they did not. Mean metolachlor concentrations under both management systems were below these guidelines. It should be noted that the manufacturers have recently voluntarily modified the permitted use patterns for atrazine to improve water quality, and the original formulation of metolachlor has been voluntarily withdrawn from use in Canada.

Prairie Provinces

In the Prairies, relatively little pesticide is used per hectare compared with other agricultural regions. Although this level of usage greatly reduces the risk of large quantities of pesticides entering surface water, several features of the Prairies make surface water susceptible to pesticide contamination. For example,

- many prairie watersheds produce little runoff, so pesticide concentrations in runoff can be relatively high
- dry surface conditions and long frozen periods greatly reduce the microbial breakdown of pesticides
- the period of most intense rains generally occurs in June and July, when most pesticides are applied.

The greatest loss of surface-applied pesticides into the prairie environment seems to be through

volatilization into the atmosphere. In general, most pesticides found in surface water come from the atmosphere, but in some instances high concentrations derive from runoff. The occasionally high concentrations of pesticides in spring melt may result from the buildup of pesticides from the atmosphere in the winter snowpack.

During the 1960s and 1970s, surface waters in the Prairies had relatively high concentrations of alpha-HCH, an insecticide not used in Canada or the United States. The source was believed to be atmospheric transport, probably from Asian countries where large quantities of this insecticide were used by farmers. In recent decades, levels of alpha-HCH have declined in prairie waters and elsewhere in the northern hemisphere, probably because it has been replaced by lindane. Lindane is found throughout the globe, often in regions distant from areas of use, providing strong evidence of atmospheric transport. Research reported in 1997 indicated that this insecticide is accumulating in Arctic ecosystems (e.g., in water, fish, and wildlife), where it is a concern to northern Canadians. Lindane is used in the Prairies as a seed treatment for canola.

Pesticides are often detected in irrigation return flows, streams, rivers, lakes, and wetlands. Except for wetlands, concentrations are usually below water quality guidelines. Research reported in 1999 showed that levels of some pesticides in



Pesticide application

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Effect of atmospheric deposition on surface water quality

Many chemicals, including acids, metals, and organic contaminants, are deposited from the atmosphere onto the land or water. They may be deposited in precipitation (wet deposition) or as particles or gases (dry deposition). Chemicals deposited from the atmosphere may enter surface waters directly (important for lakes, especially those with significant water-retention times) or in surface runoff from land. Much of this atmospherically transported material originates outside Canada's borders.

Acid rain is caused by the emission and atmospheric transport of sulfur and nitrogen pollutants. With a few local exceptions, the acidity of atmospheric deposition is highest in that part of Canada east of the Ontario-Manitoba border and south of James Bay. Canada's best agricultural soils (found in the Prairies, southern Ontario, the Ottawa and St. Lawrence river valleys, and the regularly limed fields of Prince Edward Island, New Brunswick, and Nova Scotia) are the ones most likely to have the properties needed to neutralize this acidity. Thus, surface water acidification almost never occurs in areas of major agricultural activity. Even if the soil gradually loses its capacity to neutralize acidity by leaching of base cations, it is likely that liming or other soil amendment to increase crop yield will occur long before there is any sign of increased acidity in runoff waters.

Metal concentrations in atmospheric deposition are much smaller than those in several common soil amendments such as superphosphate, sewage sludge, or cow manure. As long as soil conditions do not yield acidified runoff, metals added to soil will be largely retained. If the soil acidifies, however, the stored metal burden may be mobilized and leach into surface water or groundwater.

Recent studies have shown that the atmosphere may also be a significant pathway for organic contaminants to enter rural waters. This is particularly true for persistent organic pollutants such as the older organochlorine insecticides (e.g., DDT), as well as industrial compounds such as polycyclic aromatic hydrocarbons (PAHs), and polychlorinated biphenyls (PCBs), all of which are typically poorly soluble in water and highly adsorbed to particulate matter. Newer pesticides are generally more water soluble, less strongly adsorbed to particulate matter, and less persistent in both the terrestrial and aquatic environments than the older contaminants but have still been found in precipitation at many sites.

Organic contaminants differ from most acids and metals in that they also volatilize from soils or surface waters. Post-application volatilization of pesticides is a major source that may account for their occurrence in surface waters where they have not been used locally or not for many years. Depending mainly on the type of pesticide, its vapour pressure at the soil or water surface, water solubility, and the rate at which it leaches away from the soil surface, less than 1% to 90% of an applied pesticide may be lost through volatilization within days of use.

D.A. Jeffries, National Water Research Institute

many prairie wetlands exceeded guidelines for protecting aquatic life following high precipitation events in late June and early July. For example, in 1993 an estimated 24% of the small wetlands in Saskatchewan had pesticide levels in water that exceeded these guidelines. Lindane and triallate concentrations exceeded guidelines (0.01 and 0.24 microgram per litre, respectively) most frequently.

In a recent Alberta study (1992-1996), pesticides were detected in 44% of stream samples and 51% of lake samples. All concentrations were below water quality guidelines for drinking water. Two of 115 samples exceeded guidelines for protecting aquatic life. Guidelines for irrigation water were exceeded more frequently. Concentrations of the herbicide MCPA exceeded irrigation guidelines in 25% of samples taken from streams and lakes in watersheds with intensive and moderately intensive agriculture. Concentrations of another herbicide, dicamba, exceeded the irrigation guidelines in 6% and 9% of the stream and lake samples, respectively. In general, pesticides were detected more frequently and at higher concentrations in watersheds with intensive agriculture.

Irrigation return flows monitored in Saskatchewan in 1994-1996 sometimes contained the herbicides dicamba, MCPA, and diclofop at concentrations above guidelines for aquatic life. Maximum concentrations of these pesticides in irrigation runoff have also exceeded guidelines for irrigation water. Herbicides have also been detected in surface waters in several studies in Manitoba (e.g., of the Cooks Creek and South Tobacco Creek watersheds, and the Red River and eight of its tributaries). However, concentrations were generally below the Canadian guidelines for aquatic life.

Not all pesticides in prairie surface waters come from agriculture. For example, higher concentrations of herbicides such as 2,4-D have been observed downstream of Edmonton and Winnipeg than upstream of these cities. This increase has been attributed to the use of 2,4-D on lawns, parks, and golf courses. Some cases of contamination of surface water have been attributed to weed control in roadside ditches and rights of way.

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Acid rain is caused by the extensive wet and dry deposition of sulfur and nitrogen pollutants. With a few local exceptions, the acidity of atmospheric deposition is highest in the east part of Canada east of the Ontario-Alberta border and south of James Bay. Canada's first agricultural soils (found in the Prairie provinces, Ontario, the Yukon and N. Labrador river valleys, and the heavily forested hills of Prince Edward Island, New Brunswick, and Nova Scotia) are the most acid likely to have the properties needed to neutralize the acidity. These surface water neutralization ability tests were used to assess if water agricultural lands. Even if the soil partially loses its capacity to neutralize acidity by leaching of base cations, it is likely that leaching of other soil constituents to increase crop yield will occur long before there is any sign of increased acidity in surface waters.

Most concentrations of atmospheric deposition are much smaller than those in several common soil constituents such as superphosphate, sewage sludge, or lime stones. As long as soil conditions do not yield significant runoff, no risk added to soil will be largely contained. If the soil conditions, however, the acid rain runoff may be mobilized and leach into surface water or groundwater.

Recent studies have shown that the atmosphere may also be a significant pathway for organic contaminants to enter surface waters. This is particularly true for persistent organic pollutants such as the other organochlorine insecticides (e.g., DDT), as well as halogenated compounds such as polycyclic aromatic hydrocarbons (PAHs), and polychlorinated biphenyls (PCBs), all of which are typically poorly soluble in water and highly adsorbed to particulate matter. These pollutants are generally more water soluble, less strongly adsorbed to particulate matter, and less persistent in both the terrestrial and aquatic environments than the other contaminants but have still been found in precipitation at high rates.

Organic contaminants like PCBs were found and mobile in that they also migrate from soil to surface waters. First, precipitation volatilization of pesticides is a major source that may account for their occurrence in surface waters where they have not been used locally or just for short years. Depending strictly on the type of pesticide, its vapour pressure at the soil or water surface, water solubility, and the rate at which it leaches away from the soil surface, less than 1% to 10% of an applied pesticide may be lost through volatilization within days of use.

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For more information, see the following sources:

Central Canada

Pesticides tend to occur more frequently in surface waters in the humid regions of Canada than in the Prairies. Here, measured total losses of pesticides into surface water have represented 1 to 2% of the applied amount.

In a study carried out in eight tributaries of Lake Erie from June to November 1998, it was found that at least one pesticide was present in each river during this period. One or more of the herbicides atrazine, metolachlor, and dicamba was detected in six of the eight rivers and creeks, mostly in June and July. Detections were generally below Canadian water quality guidelines for aquatic life. Studies of field-sized areas of corn in eastern Ontario from 1991 to 1994 showed that atrazine, widely used on corn, was present in most samples of tile drainage water, but at levels generally below the *Canadian interim maximum acceptable concentration* of 5 micrograms per litre.

Two streams flowing through Ontario's Niagara fruit-growing region were monitored for the presence of insecticides during 1996 and 1997. Four insecticides (azinphos-methyl, diazinon, chlorpyrifos, and endosulfan) were detected regularly, at frequencies ranging from 15 to 97% of the samples. Concentrations of all four frequently exceeded Canadian water quality guidelines for aquatic life or, where these have not been established, the Ontario water quality objectives for aquatic life (46–100% of detections). Detections occurred most frequently during periods of insecticide application and may have been the result of spray drifting into the water. In contrast, in the intensive vegetable-growing area on the organic soils of the Holland Marsh, where insecticide use is high, a 1991–1993 study detected similar pesticides less frequently and at lower concentrations in the Holland River.

Many pesticides have been detected in the St. Lawrence River and its tributaries, particularly herbicides of the group of triazines, such as atrazine, and the group of chlorophenoxyacetic acids, such as 2,4-D (Table 5-4; also see Yamaska River case study, p. 54). In some rivers draining intensive agricultural lands, atrazine concentrations exceeded the guidelines for protecting aquatic life for more than 60% of the monitored period during summer. The concentrations of many other pesticides

occasionally exceeded Canadian guidelines for aquatic life (<1 to 9% of the time). Other studies in eastern Ontario have shown that concentrations of atrazine and metolachlor tend to be highest during rainfall events in May, June, and July, when these herbicides are often used on corn.

Atrazine and metolachlor were measured in precipitation at nine sites in the Canadian Great Lakes Basin between April and December 1995. Both were detected regularly at all nine sites throughout this period. The detection of some pesticides at sites where they were not used provides evidence of atmospheric transport of pesticides in this region.

As noted for the Prairie region, urban centres also contribute pesticides to surface water. Measurements made in Guelph, Hamilton, and Toronto in 1998 showed herbicides and insecticides present in urban runoff. Two insecticides, diazinon and chlorpyrifos, had maximum concentrations that exceeded Ontario water quality objectives for aquatic life.

Atlantic Provinces

In the Atlantic provinces, 150 municipal drinking water sources were sampled for various pesticides (carbamate insecticides, organochlorines, and organophosphorus insecticides) during the late 1980s. Of the 95 sources deriving from surface waters (25% of which were in areas of moderate-to-high agricultural land use), no carbamates were detected, organochlorines were detected at very low concentrations (less than 0.01 microgram per litre), and organophosphorus insecticides were inconsistently detected at concentrations at or near the detection limit.

In a related study of the occurrence of triazine herbicides in surface waters of selected agricultural watersheds between 1983 and 1989, only atrazine was detected (in 38 of the 125 samples), at concentrations ranging from 0.01 to 0.34 microgram per litre (well below Canadian guidelines for all uses). In one case the concentration of atrazine in water at a single subsurface drain outlet in a small stream was 14 micrograms per litre, well above the drinking water guideline. However, the in-stream concentration at this outlet was 2 micrograms per litre, and no negative impacts were observed on

plankton 50 metres downstream. It should be noted that atrazine is not widely used in Atlantic Canada because of the small area of corn grown.

Pathogens

Concerns about pathogenic organisms carried by water from farmland have increased as livestock operations have intensified. In the Sumas River watershed of British Columbia, where agriculture is dominated by dairy production, the most probable number of fecal coliforms ranged on average from 42 to 709 per 100 millilitres of water, nearly all measurements above the Canadian water quality guidelines for both drinking and irrigation water. Counts were two to eight times higher on wet days than on dry days. The Sumas River itself showed the highest concentrations, making this water unsuitable to irrigate vegetables eaten raw.

In monitoring 27 Alberta streams during 1995 and 1996, it was found that more than 90% of samples exceeded the drinking water guidelines for fecal coliforms, but no relationship with agricultural intensity was established. A lower share (48%) was found to exceed recreational water guidelines for total enterococci bacteria. In sampling 112 Alberta dugouts, which are widely used in the Prairies as a source of domestic water on farms, 68% were found to have fecal coliforms exceeding drinking water guidelines.

Intensified livestock production in an Ontario region has not been linked to increasing abundance of bacteria in streams (see Case studies on surface water quality in rural Ontario, p. 53). However several studies have reported increased fecal bacteria counts in runoff from manure-treated fields. In Quebec, intensive hog production is raising concerns about bacteria contaminating streams. However, manure storage

Table 5-4
Water quality in relation to pesticides in four rivers located in Quebec's intensive corn-cropping areas, 1992 to 1995

Pesticide	Frequency of detection, 1992-1995 (%)	Frequency of exceeding Canadian Water Quality Guidelines (%)							
		Aquatic life guidelines				Drinking water guidelines			
		1992	1993	1994	1995	1992	1993	1994	1995
Herbicides: Atrazine	100	43	36	23	16	22	12	10	6
Metolachlor	94	0	2.5	2.8	1.7	0	0	0	0
Cyanazine	67	0	0.8	2.1	1.4	0	0	0.7	0
Insecticides: Carbaryl	6	0	0	8.5	5.6	0	0	0	0
Diazinon	3	0	0	4.3	6.3	0	0	0	0
Malathion	2	0	0	0	0.7	0	0	0	0
Azinphos-methyl	2	0	8.8	4.3	1.4	0	0	0	0
Chlorpyrifos	1	0	0	0	3.5	0	0	0	0

Notes: The total number of samples was 441. Seven other herbicides (phenoxy and benzoic compounds) were detected although their concentrations did not exceed Canadian Water Quality Guidelines. Among them, the frequency of detection was 66.4% for dicamba, 59.1% for 2,4-D, 44.3% for mecoprop and 31.2% for MCPA. Six other pesticides were detected in 3% to 67% of the samples and showed concentrations in water lower than the Canadian Water Quality Guidelines. Four additional pesticides, for which no water quality guidelines exist, were detected in trace amounts (from less than 0.2% to 20% of the samples).

Source: Giroux et al., 1997

tanks constructed since 1988 have reduced direct manure losses to streams (see Chapter 8).

Cryptosporidium and other parasitic organisms are occasionally found in surface water. These include organisms such as *Giardia*, which can be present in the excreta of wildlife and sometimes of livestock. Proper chlorination or other treatment is required before this water is used for human or livestock drinking.

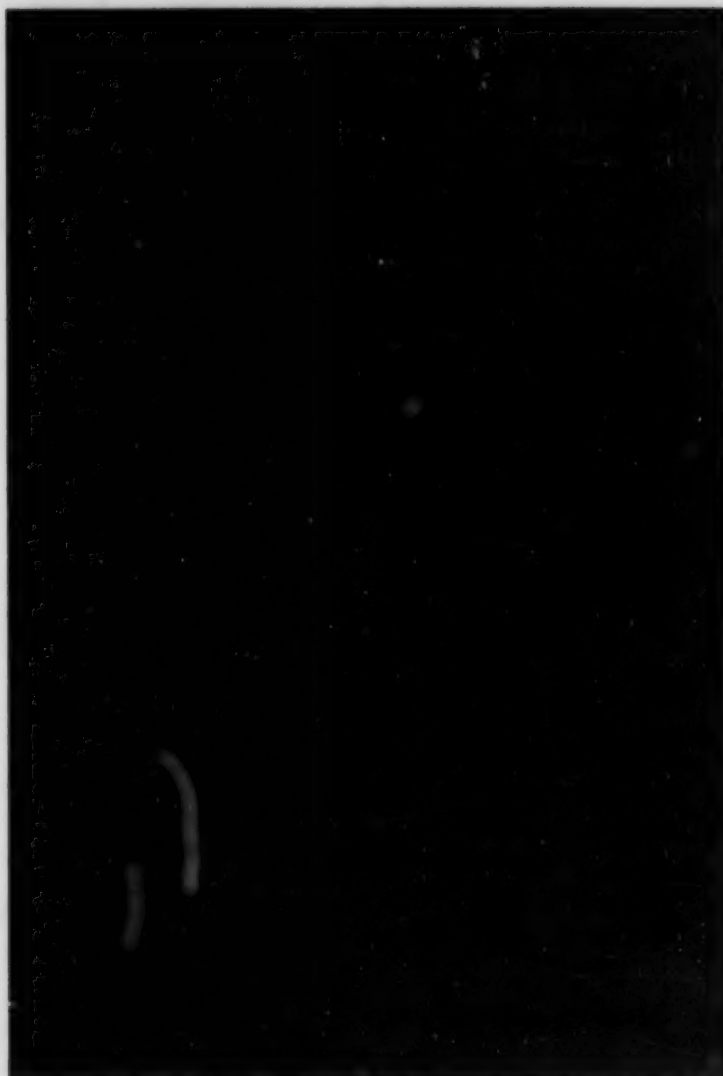
The east coast shellfish industry is particularly vulnerable to bacterial contamination. Agricultural runoff containing coliform bacteria is believed to be a major nonpoint source of pollution affecting shellfish-growing areas in Atlantic Canada and has been directly implicated in some shellfish closures.

Metals

The 1994 study of the Sumas River watershed in British Columbia showed that some metal concentrations occasionally exceeded Canadian or provincial guidelines, or both. For example, concentrations exceeded Canadian guidelines for aquatic life on two sampling dates for total iron at all nine sampling sites and for total aluminum at all but one site. After a week of steady rain, the Canadian and provincial guidelines for protecting phytoplankton and zooplankton were exceeded for chromium, copper, and nickel at all or many of the sites; at two sites, the guideline for protecting fish was exceeded for chromium. No sources of these heavy metals were identified, and it is likely that they represent background levels for the soils and geologic conditions in this watershed.

It was reported in 1992 that contamination of surface water in the province of Quebec by heavy metals was insignificant. However, a survey conducted between 1987 and 1990 found that 10% of the agricultural land in monoculture had elevated levels of heavy metals. Increased zinc and copper levels in the soil were associated with high animal density and likely resulted from manure being applied. During the 1970s, only 1 of 11 watersheds studied in Ontario had elevated heavy metal contents in stream sediments and water. These were traced to high natural levels of these elements in groundwater entering the stream from bedrock that was naturally rich in these metals. No relationship was found between

agricultural activities and heavy metals in surface water in this study. Using municipal sewage sludge on farm land has raised concerns about heavy metal contamination but does not seem to be a problem if guidelines are followed (see Box).





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Municipal waste disposal on agricultural lands

Sewage sludge is an organic by-product of wastewater treatment. Also called biosolids, this organic material is useful as a soil amendment because it contains nitrogen, phosphorus, and other crop nutrients and adds organic matter to the soil. Land application of sewage sludge is an effective means of organic recycling and provides economic benefits to the agricultural community and municipal taxpayers.

In Ontario, researchers at the University of Guelph and Elora Research Station carried out water- and soil-quality studies in the 1970s to assess the movement of pathogens, metals, organics, and nutrients from land of varying slopes that received sewage sludge. Results indicated no reason for concern for downstream water quality when application practices conformed with guidelines developed during the studies. These guidelines have since been revised and are among the strictest in the world.

More than 80% of Ontario municipalities have land-use programs, annually applying more than 1.5 million tonnes of biosolids on 13 000 hectares of agricultural land. The Ontario government supports this practice, provided that

- treatment of biosolids produces a stable organic material
- application rates are based on crop requirements
- municipalities analyze biosolids for nitrogen, phosphorus, and metals, and that amounts of these compounds do not exceed guidelines
- biosolids are only applied to suitable soils, as indicated by the guidelines
- separation distances to residences, wells, and water sources comply with topographic criteria.

Today many municipalities in Canada apply biosolids to agricultural land. Guidelines for this practice exist in Ontario, Manitoba, Alberta, Quebec, and New Brunswick. British Columbia, Saskatchewan, and Nova Scotia have draft guidelines.

P. Sidhwa, Terratec Environmental Ltd.

Organic matter

Aquatic vegetation and manure that reaches surface water introduce high particulate and dissolved organic matter into the water. These compounds often impart undesirable colour, taste, and odour to the water. If particulate organic matter is not completely removed as part of water treatment, protozoan human parasites such as *Cryptosporidium* can become surrounded by the organic matter and escape disinfection during chlorination. Chlorinating water that has not first been treated to remove dissolved organic matter produces a number of suspected cancer-causing compounds, such as trihalomethanes. Median levels of dissolved organic carbon in small reservoirs in Saskatchewan were found to be about 11 milligrams per litre, sufficiently high to produce trihalomethanes exceeding drinking water guidelines if the water is not treated to remove organic carbon prior to chlorination.

Conclusion

Surface waters in Canada range from poor to good quality. Agricultural impacts on surface waters are common, particularly after rainfall events.

In general, the problem of soil erosion by water and wind is decreasing in Canada, mainly because of the use of conservation farming practices such as reduced tillage and no-till and residue management. However, cropland used to grow row crops, especially rolling land with vulnerable soils (e.g., south central British Columbia, New Brunswick, and Prince Edward Island), will continue to be at risk of erosion unless more care is taken to keep the soil covered and to adopt conservation practices such as contour strip cropping and terracing. Soil erosion figures can give only an estimate of the actual sedimentation of surface waters, for which better data are needed in many agricultural areas. Curbing the rates of erosion and sedimentation also helps to reduce the amount of nutrients, pesticides, and other substances that reach water attached to soil particles.

Eutrophication caused by nutrient inputs from agricultural sources has been observed in the Fraser Valley of British Columbia, the southern

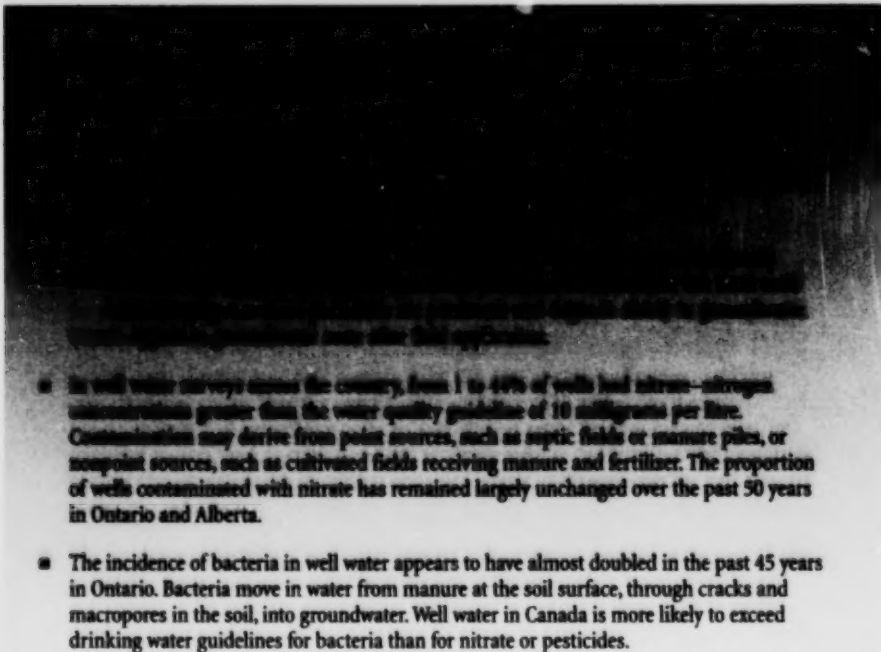
Prairie provinces, watersheds draining into lakes Erie and Ontario, and the south shore of the St. Lawrence River. Even without knowing exactly how much nutrient loading of surface waters can be attributed to agriculture, it makes sense to manage agricultural nutrients carefully, especially in these areas of intensive agriculture.

Pesticide concentrations in surface waters vary considerably across Canada. Although pesticides are detected in surface waters in many agricultural watersheds, concentrations are typically below Canadian water quality guidelines for drinking water but not for the protection of aquatic life. Wind-borne pesticides can be deposited on surface waters some distance from the source. Higher pesticide concentrations in water are associated with intensive crop production or poor management practices by some growers.

The intensity of agricultural activities continues to increase at the same time that urban populations are moving more into rural areas. Rural residents will continue to demand good quality surface water, while sometimes contributing to water quality problems themselves. Farmers too are more and more aware of the quality of the waters around them and are generally anxious to minimize any harmful effects of their practices. Improved management techniques (see Chapter 8) are helping to improve surface water quality, but farmers and rural residents must remain committed to this improvement if it is to be sustained.

6. Groundwater Quality

G.L. Fairchild, D.A.J. Barry, M.J. Goss, A.S. Hamill, P. Lafrance, P.H. Milburn, R.R. Simard, and B.J. Zebarth



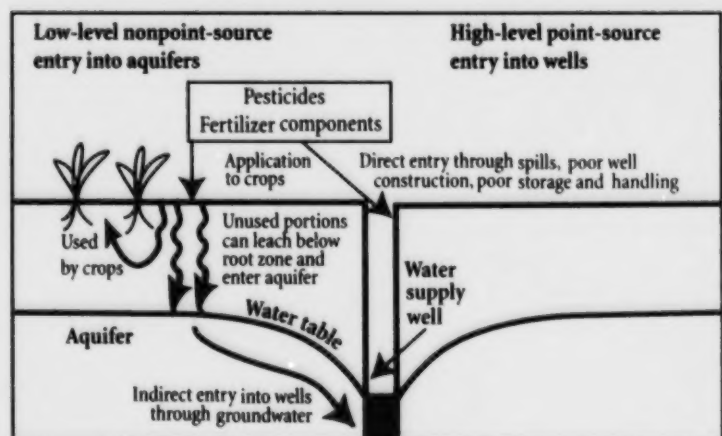
Introduction

Groundwater pumped from aquifers supplies drinking water to about 26% of the Canadian population (1981 data) and about 89% of farms. It also contributes substantially to wetlands, rivers, streams, and lakes in many parts of Canada. Thus, groundwater is an important resource that must be protected from the entry of potentially harmful substances (Fig. 6-1).

Agrochemicals can enter groundwater by

- point-source contamination, such as seepage into drinking water wells because of accidental spills, poor well construction, or improper practices in storing and handling pesticides or fertilizers
- nonpoint-source contamination, which occurs over large areas, such as agricultural regions and watersheds, and is mainly caused by the slow downward movement of agrochemicals through the

Figure 6-1
Entry of agricultural substances into groundwater



Source: Acton and Gregorich, 1995

6. Groundwater Quality

G.L. Fairchild, D.A.J. Barry, M.J. Goss, A.S. Hamill, P. Lafrance, P.H. Milburn, R.R. Simard, and B.J. Zeburth

Highlights

- Nitrate contamination is agriculture's chief environmental effect on groundwater quality. Nitrate is a soluble form of nitrogen that is usually not adsorbed much by soil particles and therefore can leach into groundwater, if not absorbed by plants. Nitrate contamination of groundwater is more likely in areas of coarse-textured soils, irrigated agriculture or heavy rainfall, and intensive cropping or livestock production.
- Pesticides can be found in groundwater in most areas where they are used, but nearly always well below water quality guidelines. Some pesticides detected have not been used for years, showing that these pesticides are persistent and degrade slowly in groundwater. Others appear in groundwater soon after field application.
- In well water surveys across the country, from 1 to 44% of wells had nitrate-nitrogen concentrations greater than the water quality guideline of 10 milligrams per litre. Contamination may derive from point sources, such as septic fields or manure piles, or nonpoint sources, such as cultivated fields receiving manure and fertilizer. The proportion of wells contaminated with nitrate has remained largely unchanged over the past 50 years in Ontario and Alberta.
- The incidence of bacteria in well water appears to have almost doubled in the past 45 years in Ontario. Bacteria move in water from manure at the soil surface, through cracks and macropores in the soil, into groundwater. Well water in Canada is more likely to exceed drinking water guidelines for bacteria than for nitrate or pesticides.

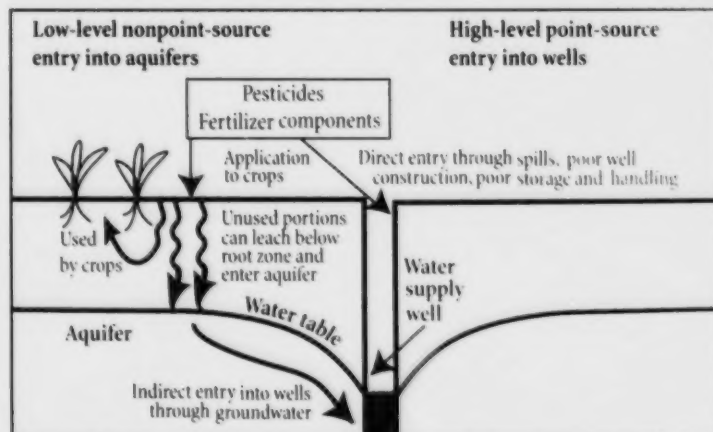
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soil profile and into the groundwater underlying farmland.

Point-source pollution of groundwater is usually localized, often non-agricultural, and fairly easy to control by education and regulation. Nonpoint-source leaching is more difficult to control because

- it can be widespread but it doesn't occur on all agricultural land, and where it does occur, it is often at very low levels
- the sources and the leaching behaviour of some materials are not well understood
- it can occur even where agricultural practices are designed to minimize soil and water degradation.

The main agricultural contaminants that leach into groundwater are nitrate, pesticides, and bacteria. Each is discussed below, highlighting provincial or regional surveys and research that illustrate findings in different parts of the country and under various production systems.

Nitrate

Numerous studies worldwide show that nitrate levels in groundwater are often higher in areas of intensive agriculture. Nitrate is a highly soluble form of nitrogen that leaches easily through the soil profile.

Nitrate leaching is most likely to happen in areas

- of intensive cropping of corn, potatoes, and specialty crops, such as vegetables and fruit, where large amounts of nitrogen are often applied

- of intensive livestock operations, where the amount of manure being applied to soil may provide nitrogen in excess of crop needs
- where irrigation is practised, because of the increased potential for downward movement of water
- receiving a heavy rainfall, especially in the spring or fall when water and nutrient uptake by crops is low
- where methods and timing of nitrogen application have not been adjusted to match crop needs
- where soil is highly permeable (e.g., sandy soils or fine soils with cracks, worm holes, and root channels), has little ability to bind chemical compounds, or both.

In a given rainfall area, annual crops (which have high nitrogen needs, are started on bare soil, possess a shallow root system, and are harvested in late summer or early fall) are more prone to leaching losses than perennial plants (which take up soil nitrogen from early spring to late fall). Land uses in the order of increasing potential for nitrate leaching are generally woodland, permanent pasture, cereals, silage grasses, row crops, horticultural crops, and legumes that are plowed down early in the fall. However, an Ontario groundwater survey did not demonstrate major differences in nitrate leaching between cropping systems.

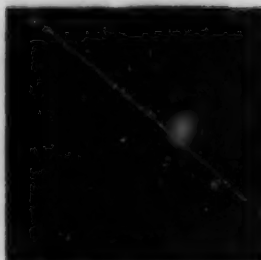
Nitrate leached into groundwater that contains sufficient organic matter and the right kind of micro-organisms can be converted into gaseous forms of nitrogen, which are then released to the atmosphere. This *denitrification* reduces the concentration of nitrate in the groundwater but adds various nitrogen oxides to the atmosphere, contributing to the *enhanced greenhouse effect* and potentially to *global warming*. The extent and importance of this process in Canada has not yet been thoroughly measured.

British Columbia

Aquifers are an important source of water for municipal, domestic, and agricultural use in arable valleys of British Columbia. The aquifers in the interior plateau and most of the Peace River area are considered at low risk of nitrate contamination because of low rainfall and generally low-intensity agriculture. In southern



Irrigation



Intensive cropping



Intensive livestock production



British Columbia, however, some aquifers are at moderate-to-high risk of nitrate contamination because of

- intensive production of livestock, crops, or both
- use of irrigation
- the predominance of coarse, sandy soils.

The aquifers in the lower mainland are particularly vulnerable, because this area also receives heavy winter rainfall. A major concern is the Abbotsford–Sumas Aquifer, which supplies

drinking water to 100 000 people in Canada and the United States (*see Box*). Nitrate concentrations exceed the Canadian drinking water guideline of 10 milligrams of nitrate–nitrogen per litre in about half of the aquifer and have been as high as 40 milligrams per litre in individual wells. The aquifer covers about 100 square kilometres south and west of Abbotsford in the Fraser Valley and about the same area in Washington state. Because groundwater in the aquifer flows south, water entering the U.S. portion is already laden with

Agriculture over the Abbotsford-Sumas Aquifer in British Columbia

Overlying the Abbotsford-Sumas Aquifer is productive farmland, home to a large rural population and the site of intensive animal and crop production. Today, much of the land is used to produce horticultural crops, particularly raspberries, and a significant area is in pasture and forage grass. Poultry layer and broiler production dominate animal operations, but there is also some dairy and beef production.

The risk of nitrate contamination of aquifer waters is estimated to have doubled between 1971 and 1991, mainly because of

- a decrease in the agricultural land base, but no corresponding decline in the volume of animal production
- a shift from beef and dairy production, which requires a local land base to produce feed, to poultry production, which does not. This shift allowed land to be taken out of forages and pasture, which have high nitrogen needs, and put into raspberry production, with low nitrogen needs.

The combination of intensive poultry and raspberry production is the main cause of nitrate leaching from agricultural lands. All poultry feed is imported from outside the Fraser Valley, resulting in a net accumulation of nitrogen over the aquifer. For example, only about 50% of the nitrogen imported in feed for broiler and layer operations and about 20% of that imported in feed for turkey operations is exported as animal products (meat and eggs). Much of the remaining nitrogen remains in the animal manures. For economic reasons, this manure is often transported only short distances before being applied to the land.

Raspberry is the main crop over the aquifer and, as a result, receives much of the poultry manure. The nitrogen requirement of the raspberry crop is generally small, mainly because of the wide row spacing (3 metres) and the small amount of the nitrogen removed when the berries are harvested. Consequently, the potential for nitrate leaching from manured raspberry fields is very high.

Producers and others have responded to the issue of nitrate contaminating the aquifer in a number of ways that include

- developing an industry-led program to truck poultry manure off the aquifer. By 1997 about 15% of the manure produced over the aquifer was being removed to areas in the Fraser Valley with low livestock densities or to the province's interior. The target is to truck about 50% of the manure off the aquifer
- developing and transferring new technologies, such as growing cereal cover crops between raspberry rows to reduce nitrate leaching losses, applying poultry manure at rates that match crop needs for nitrogen, adjusting rates of applying nitrogen fertilizer to account for manure nitrogen, and using new ways to apply manure, such as banding, that increase the efficiency of nitrogen use
- creating the Abbotsford Aquifer Stakeholder Committee in the local community, with the goal to identify voluntary actions that stakeholders can take to help reduce the risk of contamination from any source and to launch new initiatives to help address these issues
- enforcing regulations to heighten awareness among producers. For example, helicopter flyovers have been used to identify uncovered poultry manure piles in the fall and winter.

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British Columbia, however, some aquifers are at moderate-to-high risk of nitrate contamination because of

- intensive production of livestock, crops, or both
- use of irrigation
- the predominance of coarse, sandy soils.

The aquifers in the lower mainland are particularly vulnerable, because this area also receives heavy winter rainfall. A major concern is the Abbotsford-Sumas Aquifer, which supplies

drinking water to 100,000 people in Canada and the United States (see Box). Nitrate concentrations exceed the Canadian drinking water guideline of 10 milligrams of nitrate-nitrogen per litre in about half of the aquifer and have been as high as 40 milligrams per litre in individual wells. The aquifer covers about 100 square kilometres south and west of Abbotsford in the Fraser Valley and about the same area in Washington state. Because groundwater in the aquifer flows south, water entering the U.S. portion is already laden with

Ontario farm groundwater quality survey

In 1991 and 1992, Agriculture and Agri-Food Canada sponsored a survey of water quality in farm drinking-water wells. The survey was carried out by a consortium of the Ontario Soil and Crop Improvement Association, the universities of Guelph and Waterloo, and the Ontario ministries of Health; the Environment; and Agriculture, Food, and Rural Affairs. Four farm wells were chosen in each township where more than 50% of the land area was used for agricultural production. Elsewhere, one well per township was usually sampled. Within each township, the types of farming activity and dominant soils were additional criteria for selection. Each participating farm household completed a questionnaire about their well construction, distance to potential point sources of contamination (septic system weeping beds and tanks, feedlots or exercise yards, and manure storages), use of manure and fertilizers, cropping system, pesticide usage, and petroleum storage. The network included almost 1300 of the estimated 500 000 water wells in Ontario.

None of the point sources investigated contributed significantly to the general level of contamination of farmstead domestic wells by nitrate-nitrogen. Using aggregated data, no relationship was detected between the distance separating the well from potential point sources and the incidence of nitrate contamination.

The occurrence of contaminated groundwater was related to the type, depth, and age of the water well. Contamination occurred more frequently

- in dug and bored wells or shallow sandpoints than in drilled wells, regardless of depth
- at lesser depths in all wells
- in older wells, especially shallower, non-drilled wells.

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nitrate, which limits its uses there and makes protecting the aquifer an international concern.

Agriculture has been identified as the main, though not the sole, contributor of nitrate to waters of the Abbotsford-Sumas Aquifer. The combination of intensive poultry and raspberry production over the aquifer is the main source of nitrate. A number of measures are now in place to reduce nitrate leaching into the aquifer.

Prairie Provinces

Because nitrate leaching depends on water moving down through the soil profile, the risk of nitrate contaminating the groundwater is thought

to be low in the dry prairie of southern Alberta and Saskatchewan. This area is characterized by soil moisture deficits and low-intensity farming (mainly grain and low-density grazing of livestock). As well, extensive areas of clayey tills overlying glacial and bedrock aquifers slow the downward movement of water and the leaching process. Intense storms can, however, move nitrate through fractured surface materials to the groundwater.

Much of Alberta's groundwater is obtained from deep bedrock aquifers not directly linked to the soil surface. A 1995-1996 survey of Alberta farm wells indicated that only 0.6 % of 448 deep wells had nitrate-plus-nitrite levels above the Canadian water quality guideline for drinking water, but 13% of 376 shallow wells exceeded the guideline.

High nitrate levels have been recorded in groundwater in areas where only geologic sources were present, showing that agriculture is not always the source of nitrate. Where agricultural sources of nitrate were likely, such as in tile drainage water and in wells located on farms, 5 to 25% of samples contained nitrate-nitrogen above the guideline for drinking water. The same degree of contamination was reported in the 1940s, so nitrate levels may not be increasing under current agricultural practices.

A 1995 survey of 85 Saskatchewan wells likely to be contaminated because they were shallow (less than 20 metres deep), in unconfined aquifers, and in agricultural areas showed that 33% of the wells contained nitrate above the drinking water guideline. Another survey in 1996 of shallow wells in other agricultural areas of Saskatchewan found that 36% had nitrate above the drinking water guideline.

Central Canada

Central Canada's prime agricultural regions have diverse combinations of intensive agriculture, wet climate, highly permeable soils, shallow soils, and high water tables. As a result, there is a high risk of nitrate and other agrochemicals leaching into the groundwater in areas where several of these factors occur together.

Groundwater provides a small part of all water requirements in Ontario, but farm families depend almost entirely on this source for their water. An extensive survey of farm drinking water

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Prairie Provinces

Because nitrate leaching depends on water moving down through the soil profile, the risk of nitrate contaminating the groundwater is thought

Table 6-1
Results of Ontario well water surveys

Survey years	Number of wells	% of wells		
		Nitrate–nitrogen >10 mg N/L	Coliform bacteria >10/100 mL	Pesticide detections
1950–1954	484	14	15 ^a	-
1980	37	5	43	-
1954–1985	63	21	-	-
c. 1985	49	5	-	-
1979–1984	359	-	-	37
1981–1984	102	-	-	14
1984	91	-	-	13
1986	103	15	-	10
1987	76	7	-	5
1990	566	12	37	-
1991–1992	142	7	44 ^b	-
1991	301	15	34 ^b	10
1991–1992	1292	14	34, 25 ^a	12

^a data for *E. coli*.

^b data for fecal coliform.

Source: Goss et al., 1998

wells was conducted in Ontario in 1991–1992 to determine

- the quality and safety of drinking water for farm families
- the effect of agricultural management on groundwater quality at a provincial scale.

Of 1292 farm wells tested, 14% exceeded the Canadian drinking water guideline for nitrate–nitrogen. The occurrence of groundwater contamination was related to the type, depth, and age of the well (see Box, p. 64).

Table 6-1 presents the results of groundwater surveys carried out in Ontario since the 1950s. The share of wells with nitrate levels of more than

10 milligrams per litre recorded in 1991–1992 did not differ significantly from that reported in 1950–1954. Surveys carried out between these dates indicated that about 5 to 20% of drinking water wells had levels of nitrate greater than the Canadian drinking water guideline. These results suggest that agricultural activity over the past 50 years has not significantly changed the amount of nitrate added to groundwater.

Multi-level monitoring wells were also installed in farm fields and woodlots adjacent to the drinking water wells at 144 survey farms. Nitrate concentrations exceeded the Canadian drinking water guideline for more than half the sampling intervals at 23% of the field multi-level sites. The

average concentration of nitrate-nitrogen in these wells decreased from about 10 milligrams per litre near the water table to 3 milligrams per litre at a depth of about 6.5 metres. The share of contaminated wells was similar for both the drinking water wells and field multi-level wells in the survey, indicating that contamination is caused as much by activities on the cultivated fields as by on-farm point sources of contamination.

Although well surveys lack precision in evaluating the effects of specific farming or cropping practices, it was observed that

- farms where manure was spread were more likely to have wells contaminated with nitrate-nitrogen and bacteria than other farms
- uncultivated conditions in the woodlots appear to have provided an environment in which nitrate, but not bacteria, was removed from groundwater.

Nitrate contamination is a more serious problem in groundwater than in surface water in Quebec. It has been particularly associated with areas of intensive potato production. This crop is produced on sandy soils using large amounts of nitrogen fertilizers. Nitrate concentrations ~~over~~ the Canadian guideline for drinking water have been found in the aquifers that supply drinking water to several municipalities. For example, 40% of wells in the regional municipality of Portneuf have had nitrate concentrations above this guideline. Recent measurements have indicated improvements in the situation, believed to be the result of using cover crops, reducing fertilizer nitrogen inputs, and applying smaller applications of fertilizer.

Atlantic Provinces

Soil, climate, and cropping systems in the Atlantic provinces can combine to create favourable conditions for nitrate to leach from nonpoint agricultural sources. In New Brunswick and Prince Edward Island, nitrate moving from its point of origin or field application into the shallow groundwater has been studied by analyzing tile drainage (subsurface) water from fields with a known cropping history. Nitrate concentrations more than background levels are attributed to nonpoint-source agricultural application rather than to spills or some other point source. These studies provide an upper

estimate of the nitrate concentrations that may be contained in water percolating through the root zone and recharging deep groundwater supplies as a result of normal farm operations.

Nitrate leaching in potato, cereal, corn, and grass production systems has been investigated. Table 6-2 shows the average nitrate-nitrogen concentrations in the tile drainage water from selected Maritime crop production systems, along with similar results from intensive agricultural regions in the United States and western Europe.

Table 6-2
Mean concentration of nitrate-nitrogen
in drainage water

Crop	Location	Concentration (mg/L)
Potatoes	N.B.-P.E.I.	10-20
Cereal	P.E.I.	3-6
Corn silage	N.B.	5
Grass	N.B.	3-5
Pasture	N.B.	1-3
Corn-soybeans	Iowa	20-40
Potato-cereals	Europe	25-30
Speciality crops	Europe	35-70
Pasture	Europe	3-7

Compiled from various published sources by P.H. Milburn, Agriculture and Agri-Food Canada, and by G.L. Fairchild, Eastern Canada Soil and Water Conservation Centre.

In the Maritime studies, fertilizer nitrogen inputs were about 150, 90, and 200 kilograms per hectare for potatoes, corn, and grass, respectively. Potato production resulted in the highest concentrations of nitrate (*see* Box, p. 68). The average nitrate-nitrogen concentrations from other cropping systems were probably lower than the European and Iowa crops shown, because less fertilizer was applied and more rainfall caused greater leaching and dilution of the nitrates carried into the drainage water.

Some practices can minimize the degree of nitrate leaching (*see* Chapter 8). These are matching fertilizer application to crop needs,

Table 6-3
Average nitrate levels in groundwater in the Maritime provinces

Location and type of study	Date	Average concentration of nitrate-nitrogen (mg/L)	Wells with nitrogen concentration exceeding the guideline (%)
Carleton County, N.B., 300 farm wells	1984-1985	2-30	14-22
3 farming regions in N.B., 47 farm wells	1973-1976, 1988	9.5	20
4 watersheds of Kings Co., N.S., 237 wells	1989	4.6	13
P.E.I., 2216 drinking water analyses	1991-1994	2.7	1
1 watershed of Bedeque Bay, P.E.I., 283 wells	1995	6	7
P.E.I., 146 dairy farm wells	1997	9.9	44

Compiled from various published sources by P.H. Milburn, Agriculture and Agri-Food Canada, and by G.L. Fairchild, Eastern Canada Soil and Water Conservation Centre

using appropriate crop rotation, using cover crops and high-carbon residues where possible, using composts and manures carefully, and avoiding early fall tillage of forage crops.

Deep groundwater in areas of intense potato production in New Brunswick has been investigated using domestic and research wells. This study measured nitrate concentrations in groundwater drinking water supplies. To carry out this study, the hydrogeology of a watershed dominated by potato production was determined to a depth of 30 metres, and the watershed was instrumented to determine water quality at several depths. Average nitrate-nitrogen concentrations in private and research wells were less than the Canadian drinking water guideline of 10 milligrams per litre. However, average concentrations were higher in areas of intensive potato production than in rural, non-agricultural areas. Other examples of nitrate levels in groundwater from various studies in Atlantic Canada are given in Table 6-3.

Further details of some of these studies follow:

- In a 1989 study of rural water supplies in Kings County, N.S., well depth, well construction, and soil texture were the main factors that made wells susceptible to contamination.
- Close to one in five rural wells in the Bedeque Bay watershed in Prince Edward Island had nitrate-nitrogen

concentrations greater than 8 milligrams per litre. (This study, "Well Watch 1995," was undertaken by The Bedeque Bay Environmental Management Association.)

- A 1989-1991 provincial well study examined the link between land use and nitrate levels in Prince Edward Island groundwater. The average nitrate concentration in the wells situated in areas of intensive row crop cultivation was almost twice the provincial average and nearly five times higher than levels observed in relatively pristine areas.
- Province-wide analysis of drinking water in Prince Edward Island from 1991 to 1994 showed that 4% of supplies exceeded the Canadian drinking water guideline in locations where mean nitrate concentrations were 4 milligrams per litre or greater.

Pesticides

Pesticide contamination of groundwater is a significant public concern. Although pesticides have been detected in the groundwater of many intensively cropped areas, concentrations are mostly well below guidelines for drinking water. Specific point-source incidents of pesticide contamination also occur from time to time, such as pesticide spills or cleaning spraying equipment.

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Nitrate leaching from potato fields in Prince Edward Island

Leaching of nitrate to groundwater can occur whenever water moves through a soil containing nitrate–nitrogen. Most nitrate leaching from potato fields takes place in late fall, winter, and early spring, when there is no crop to take up nitrogen, rainfall is higher, and evapotranspiration is lower. Prince Edward Island's annual rainfall is about 1100 millimetres, of which about 400 millimetres leach through the soil (about 400 litres per square metre of land). For every kilogram of nitrate–nitrogen leached per hectare, the concentration of nitrate–nitrogen in the leached water would be 0.25 milligrams per litre. In other words, to keep contamination of groundwater by nitrate below the Canadian drinking water guideline of 10 milligrams per litre, the amount of nitrate lost from fields by leaching must be kept below 40 kilograms per hectare.

The amount of nitrogen applied to Prince Edward Island land in 1997 was an estimated

- 9 million kilograms of fertilizer nitrogen
- 7 million kilograms of manure nitrogen (from 242 thousand tonnes of hog manure, 560 thousand tonnes of beef manure, and 290 thousand tonnes of dairy cattle manure)
- 5 million kilograms of nitrogen fixed by legumes.

Even if all this nitrogen were to leach into groundwater, the resulting concentration of nitrate–nitrogen would be an estimated 9 milligrams per litre, still below the generally accepted safe limit. In reality, crops take up about 50 to 90% of available nitrogen, so the real risk of nitrate contaminating groundwater is much lower on the whole. However, in areas of intensive production of crops that use nitrogen inefficiently, such as potatoes, which may take up less than 50% of available nitrogen, the potential for leaching is much higher. Care must be taken in these production systems to match nitrogen inputs carefully to crop needs and to keep soil nitrogen levels low during the peak leaching season.



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As pesticides move toward the water table, their leaching potential is influenced by climatic conditions, the chemical and physical properties of soil, agricultural practices, and properties of the chemicals. A variety of pesticides have been identified in Canadian groundwater, but those most commonly detected

- are widely used
- degrade rather slowly
- dissolve in water
- are not tightly held by soil or organic matter particles.

British Columbia

Some soil fumigants have been widely detected in the Abbotsford–Sumas Aquifer in British Columbia, although at low levels. These compounds were used mainly in producing strawberries and raspberries but have now been removed from the market and are no longer in use. Concentrations of these compounds in aquifer waters are expected to drop over time. Elsewhere in British Columbia, various well surveys have detected a few pesticides, but generally all at sufficiently low levels not to be of concern.

Prairie Provinces

In Alberta, a 1994–1996 survey of wells showed that none of the 448 deep wells tested had pesticide concentrations exceeding the Canadian water quality guideline for human or livestock drinking or aquatic life. Less than 1% had the pesticides dicamba and bromoxynil exceeding the guidelines for irrigation water. Of the 376 shallow wells tested, irrigation water quality guidelines were exceeded by dicamba in 1%. Less than 1% exceeded the guidelines for any other use, as follows:

- 2,4-D and bromoxynil, for human and livestock drinking
- bromoxynil, triallate, and trifluralin, for aquatic life.

In 1995 and 1996 surveys of high-risk wells in Saskatchewan, pesticides were detected in 7% of wells in the first year and 26% of wells in the second year. However, all detections were at least 100 times lower than the drinking water guidelines. Most detections were of the herbicides dicamba, 2,4-D, or MCPA. Well water studies have also been done in recent years in Manitoba, and



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some pesticides were detected. However, concentrations were always below Canadian drinking water quality guidelines.

Pesticides, mainly herbicides, have been found in groundwater beneath some irrigated prairie soils. In nearly all cases, concentrations were well below the recommended limit. Residues in groundwater may vary with the condition of the site and the type of pesticide used. For example, in a 1-year study of the herbicide hexazinone on short, gravity-irrigated runs in 1991 in southern Alberta, the herbicide was detected in 50% of runoff samples and about 27% of groundwater samples. No Canadian water quality guideline exists for hexazinone, but all detections were well below the U.S. lifetime health advisory limit for drinking water of 200 micrograms per litre. In a study of phenoxy herbicides on long, gravity-irrigated runs in the same year and region, herbicide was detected in no runoff samples, but in 50% of groundwater samples. One out of six herbicides, bromoxynil, exceeded the Canadian drinking water guideline in 11% of groundwater samples.

Central Canada

Past long-term production of *monocultures* (a single crop), particularly corn and potatoes, seems to be responsible for the major cases of contaminated groundwater observed in Ontario and Quebec. Atrazine is the herbicide most often detected in groundwater, along with simazine, metribuzin, cyanazine, metolachlor, dicamba, 2, 4-D, and mecoprop. Only rarely have concentrations exceeded the water quality guidelines. New application restrictions for atrazine are expected to help reduce concentrations of this herbicide in groundwater. Among the insecticides detected in groundwater, carbaryl and carbofuran have posed the greatest concern, because concentrations have at times approached the safe limit for drinking water.

Several Ontario studies dating between 1979 and 1992 detected pesticides in 5 to 37% of wells (see Table 6-1). Dimethyl-tetrachloroterephthalate (DCCA) metabolites and atrazine were the most frequently detected pesticides. In the 1992 groundwater survey, pesticides were detected in 12% of the wells. Concentrations exceeded the Canadian drinking water guidelines in only six wells (0.3%).

A provincial survey carried out in Quebec from 1984 to 1991 found that pesticides were present in 24% of the 245 wells tested. In a limited survey in the Île d'Orléans area, 31% of wells sampled contained aldicarb and atrazine, but at concentrations below guideline levels.

Atlantic Provinces

Examples of pesticide detections in Atlantic Canada are shown in Table 6-4. In 1989, pesticides were sampled in 102 farm wells in Nova Scotia's most intensively farmed region, which includes corn cropping. Researchers detected

- atrazine (a herbicide commonly used in corn) at low concentrations (less than 2 micrograms per litre) in 32% of the wells
- at least one of nine other pesticides in 14% of the wells (at less than 1 microgram per litre)
- more than one pesticide in 19% of the wells.

The presence of most pesticides was attributed to nonpoint-source contamination and not to well construction or surficial material above the water table. In most cases, atrazine had not been used for 3 to 10 years before it was detected, indicating its persistence and slow degradation in groundwater.

Aldicarb, a rapidly leaching insecticide, was used extensively on permeable, sandy soils under potato production, particularly in Prince Edward Island (and also Quebec). Groundwater studies in the late 1980s showed that contamination of domestic wells with aldicarb was widespread, with concentrations sometimes exceeding the Canadian drinking water guideline of 9 micrograms per litre. Of the 48 wells sampled in one study, 12% exceeded the drinking water guideline. The presence of aldicarb in groundwater appeared to be related to its application at planting when soil temperatures are low and groundwater recharge is high. As a result of this information, aldicarb was removed from the market in 1990, so there is no longer a source of this substance.

Other results of pesticide monitoring include:

- Chlorothalonil, a nonleachable fungicide, was reported in 1995 not to have been found in water samples collected from domestic or research wells in an area of suspected high use in New Brunswick, and was found at concentrations just above the



Herbicide leaching under wild blueberry production in New Brunswick

On Canada's east coast, wild blueberry stands are often managed for optimal production, including the herbicide hexazinone applied to control weeds. Because blueberries grow on coarse, shallow soils and hexazinone is leachable, this herbicide has been detected in groundwater in New Brunswick, Nova Scotia, Prince Edward Island, and Maine. Concentrations are generally less than 4 micrograms per litre, but a test well in a blueberry field in Maine contained hexazinone at 29 micrograms per litre of water. No Canadian water quality guideline exists for this pesticide, but the U.S. lifetime health advisory limit for drinking water is 200 micrograms per litre.

Most data on hexazinone contaminating groundwater comes from testing domestic wells. With this approach it has been difficult to identify the main factors controlling this contamination, because local hydrogeological conditions and methods used to construct wells vary from area to area. A better approach is hydrogeological fieldwork and groundwater quality monitoring, which

- provide data on pesticides leaching from nonpoint sources (as opposed to contamination resulting from accidents or spills)
- document hydrogeological conditions prevailing at, and in the vicinity of, the sampling well
- confirm or give further insight into the likely causes of contamination.

Such a study is now being undertaken in a watershed in southwest New Brunswick where wild blueberries are produced. The study area is located on a 500-hectare glacial outwash plain consisting of sands and gravels with rapid hydraulic conductivities (in the order of 100 metres per day). The depth to the water table varies from 5 to 12 metres. A network of six multi-level groundwater observation wells has been established at selected locations within the watershed. Monthly monitoring for water quality and hydraulic head began in May 1996. Hexazinone has been applied at various locations within the plain for the past 10 years.

Results indicate that hexazinone is found throughout the watershed at concentrations of about 3 micrograms per litre or less near the surface of the water table. Concentrations decrease rapidly with depth. Nitrogen concentrations in groundwater throughout the site are negligible.

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detectable limit in 4 out of 66 drainage samples.

- Metribuzin, a leachable herbicide, was found in drainage water both in the year it was applied (1991) and again the following spring at average concentrations of 0.1 to 2% of the Canadian drinking water guideline. Concentrations in the multi-level research wells were about 0.1% of the guideline level.
- In analyses of tile drainage water from some fields and plots in production in New Brunswick during 1991 and 1995, dinoseb (a herbicide used in potato production) and atrazine (used in corn production) were found at average concentrations well below the drinking water guidelines.
- In an analysis of 16 pesticides in groundwater samples from an intensively farmed watershed in New Brunswick in 1992–1993, only the herbicides atrazine, desethyl atrazine, and metribuzin were detected, at concentrations less than 1 microgram per litre.
- In a 1996 well survey in an intensive agricultural area of Prince Edward Island, the 10 pesticides routinely targeted were not detected. However, other pesticides were detected (e.g., hexazinone).
- A continuing study of herbicides in an area of New Brunswick producing wild blueberries indicates that hexazinone is found throughout the watershed at concentrations of about 3 micrograms per litre or less near the surface of the water table. Concentrations decrease rapidly with depth (see Box).

These studies provide fairly good evidence that pesticides derived from agriculture in the Atlantic provinces have had little effect on groundwater quality.

Bacteria

The bacteria routinely measured in water quality testing are not necessarily those that cause disease. Their presence indicates the possibility that water may be contaminated by animal or human waste. They are targeted in testing because they are much easier to detect than the actual disease-causing organisms, which may be present in extremely small numbers and difficult to grow in the laboratory.

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Table 6-4
Pesticide concentrations in groundwater in Atlantic Canada

Location	Date	Pesticide	Canadian guideline for drinking water (µg/L)	Wells with pesticide detected	Mean or median pesticide concentration (µg/L)
Kings Co., N.S. 102 wells	1989	atrazine	5	33	0.24
		simazine	10	5	0.52
		metribuzin	80	4	0.02
		alachlor	no guideline	3	0.05
		metolachlor	50	2	0.86 *
		captan	no guideline	1	0.05 *
		chlorothalonil	no guideline	1	0.065 *
		dimethoate	20	1	0.40 *
N.B., P.E.I. On-farm tile drainage plots, various locations	1987-	dinoseb	10	NA	0.2
	1990	metribuzin	80	NA	0.22
		atrazine	5	NA	0.4 to 2.5
		desethyl atrazine	5	NA	less than 1.0
N.B. Wells	1990	chlorothalonil	no guideline	0	not detectable
N.B. Research multi-level wells	1996- 1998	hexazinone (Velpar)	no Canadian guideline (USEPA = 200)	6	1.5
N.B. Drainage water, research wells	1996	metalyxl (Ridomil)	no guideline	10	1
N.B. Research multi-level wells	1992- 1993	16 pesticides	various	NA	generally not detectable, or less than 1.0
P.E.I. 60 wells	1996	10 pesticides	various	0	generally not detectable

* denotes limited number of samples.

NA = not applicable

Compiled from various published sources by P.H. Milburn, Agriculture and Agri-Food Canada, and by G.L. Fairchild, Eastern Canada Soil and Water Conservation Centre.

The Canadian drinking water guidelines for coliform and *Escherichia coli* bacteria are therefore rather arbitrary values. Scientific evidence relating these limits to human health is scanty, because these organisms are not the actual causes of disease. A recent survey in Ontario found that a greater incidence of diarrhea in farm family members was associated with the detection of *E. coli* in their well water at some point during the study year. The combination of

nitrate and bacterial contamination may be important, because methemoglobinemia (see Chapter 4) has been associated with waters containing both. In general, water from drinking water wells in Canada is more likely to exceed guidelines for bacteria than for nitrate or pesticides.

In Ontario's 1992 survey of groundwater quality, 34% of the wells tested exceeded the maximum

acceptable number of coliform bacteria, and about 7% were contaminated with both bacteria and nitrate. The incidence of bacteria

- decreased with depth for dug or drilled wells but not for wells formed by a sharp point driven into sandy material (sandpoint wells)
- was higher in older wells than in younger wells.

Smaller numbers of bacteria were recorded for samples taken in the winter than in those taken in summer.

Potential point sources of nitrate or bacteria contamination, such as septic or sewage disposal systems and feedlots or exercise yards, were also investigated during the survey. The distance from a well to the weeping bed or septic tank had no influence on the level of well contamination with



Drilling a well to monitor groundwater quality

nitrate or bacteria. Feedlots and exercise yards were identified as significant localized sources of groundwater contamination with bacteria. Multi-level field wells tested in the survey were expected to separate out point-source contamination. However, in only one case was a farmstead domestic well contaminated and the multi-level well on the same farm not contaminated. In all other cases, bacterial levels were similar in drinking water wells and multi-level field wells, which suggests that the bacteria came from agricultural fields as much as from point sources.

An Ontario study using tracer bacteria showed that water flow through cracks and macropores in the soil can quickly move bacteria 100 metres or more from a septic system, manure storage, or solid beef manure. This phenomenon can result in high levels of bacteria reaching tile drainage outlets within a short time after spreading manure. Once in groundwater, bacteria appear able both to survive for several months because of the cool temperature and to multiply there.

Compared with bacterial levels measured in wells in Ontario from 1950 to 1954 (see Table 6-1), the number of wells with fecal coliform bacterial counts over the guidelines may have almost doubled over the past 45 years. In contrast, nitrate levels have remained much the same.

In the 1995–1996 Alberta well survey, 2% of the 448 deep wells tested had concentrations of fecal coliforms above the Canadian drinking water guideline, and 10% had total coliforms above the guideline. Of 376 shallow wells tested, 5% exceeded the guidelines for fecal coliforms, and 19% for total coliforms. Some data for bacteria in groundwater in other provinces are given in Table 6-5.

Other contaminants

Salt sometimes contaminates groundwater. In many regions, especially the Prairies, the salt is natural in origin and greatly limits the use of this water. In eastern Canada, salt present in groundwater sometimes comes from salt used on roads to remove ice. This source is seldom a problem for agriculture but does occasionally inconvenience rural residents.

Table 6-5
Bacterial contamination of wells outside Ontario

Province	Date	Number of wells	Share of wells contaminated with bacteria (%)	
			Total coliform	Fecal coliform
Alberta	1995–1996	824	13.8	3.6
Quebec	1990	70	26	NA
Quebec	1975–1978	216	27	14
New Brunswick	1973–1976, 1988	47	37	NA
New Brunswick	1984–1985	285	21	34
New Brunswick	1985–1986	300	29	10
Manitoba	1993	190	37	NA
Prince Edward Island	1990, 1991	42	12	NA
Nova Scotia	1989	102	9	NA

Source: Goss et al., 1998

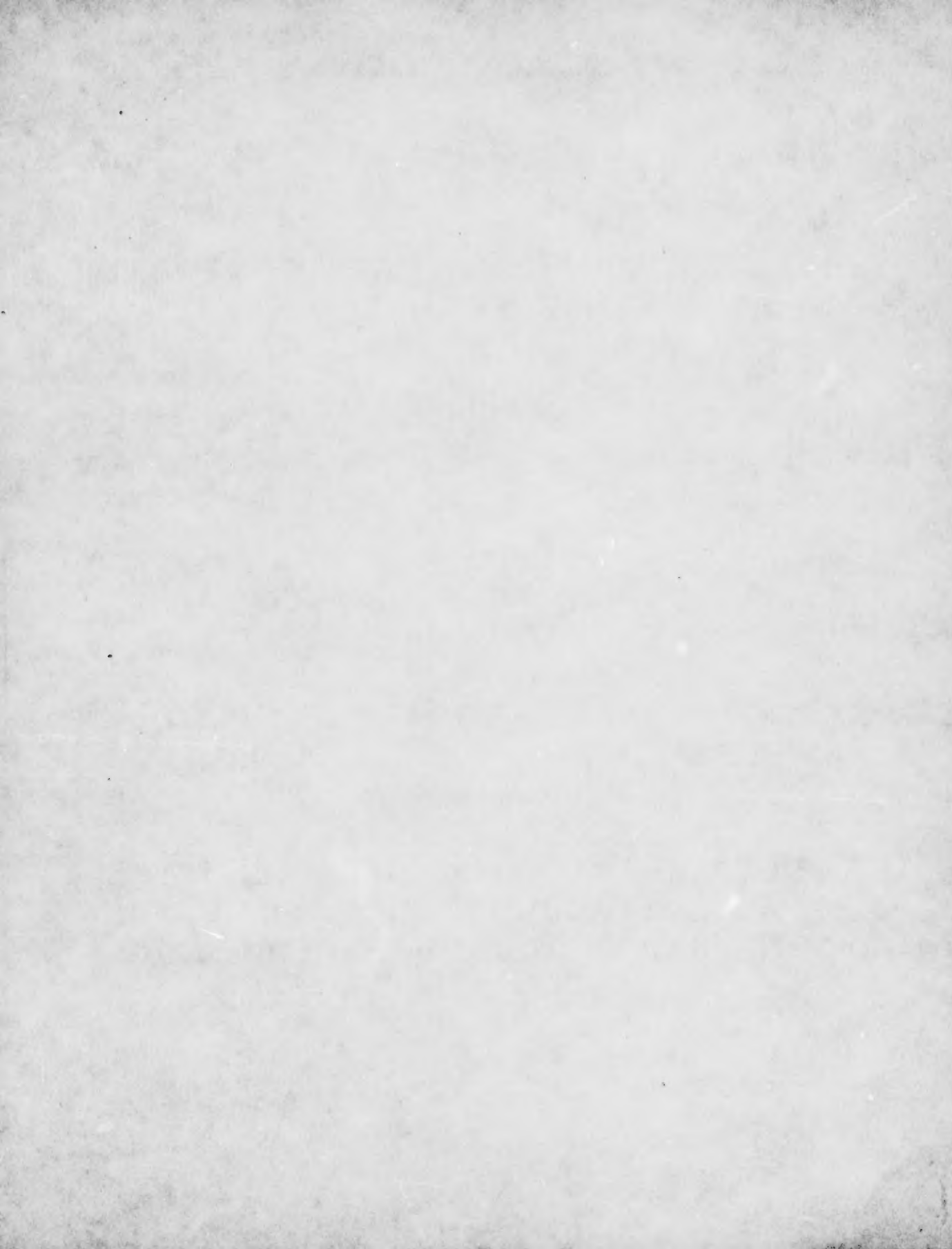
Conclusion

The impact of agriculture on groundwater quality is a concern worldwide. Elevated concentrations of nitrate have been observed in groundwater in intensively agricultural areas in many parts of the world, including the United States, United Kingdom, European Union, Australia, New Zealand, and Canada.

In Canada, groundwater quality is generally within *Canadian Water Quality Guidelines* in most areas of the country, but nitrate levels are a continuing concern. Research and surveys have shown that intensive agricultural practices may increase both the risk and incidence of nitrate contaminating groundwater. Nitrate leaching results mainly from the mismatch between crop demand for nitrate and microbial activity in the soil and is associated with all agricultural practice.

Bacterial contamination of groundwater is also observed, particularly in areas where large quantities of manure are applied. Pesticides have been detected in some groundwater, but concentrations that exceed water quality guidelines are uncommon and are usually associated with point sources, such as pesticide spills.

The prospects for improving this situation depend largely on producers who apply environmentally sound management practices (recognizing the limitations of individual farms related to climate, topography, soil, equipment, finances, and time). Although many of these practices are easy to adopt, others require an investment of time and money.



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7 Ecological Issues

L.J. Gregorich, R. Antonowitsch, J. Biberhofer, E. DeBruyn, D.R. Forder, S.F. Forsyth, P.C. Heaven, J.G. Imhof, and P.T. McGarry



- *As agriculture is altered within watersheds, its practices often interfere with watershed components and always have some effect. This effect may involve altering wildlife habitat and its ability to support a diverse biological community. Agricultural and other rural development activities often lead to land clearing, drainage, and straightening channels, which can alter the physical nature of waterways. Irrigation infrastructure often provides new aquatic habitat. Excess nutrients cause eutrophication, which depletes oxygen. Nitrogen and some pesticides may be lethal or sub-lethal to aquatic organisms when concentrations exceed threshold levels.*
- Numerous conservation projects have been undertaken in Canada to restore and improve riparian and aquatic habitat, including work on wetlands and agricultural drains. Enhancement measures not only benefit fish and wildlife but, in many cases, improve the quality of water used on the farm.
- Clean and useable waterways enhance the esthetic appeal of rural landscapes.

Introduction

Understanding the ecological issues that arise through the effects of agriculture on water is best achieved by stepping back and looking at the watershed as a whole. Geographically, a watershed is a catchment area, defined by the relief of the land that drains into (or lies upslope of) a specified point on a stream. Water that falls in this basin as precipitation is collected, stored, released, and transported by a number of landscape components. When these components are intact and functional, they moderate and extend water flow and support diverse and healthy biological communities.

The components of a watershed continually change through natural ecological processes such as vegetation succession, erosion, and the shifting of stream channels. Intrusive human activity often affects watershed function in ways that are inconsistent with the natural balance. These changes, often rapid and sometimes irreversible, occur when people

- cut forests
- clear and cultivate land
- remove stream-side vegetation
- alter the drainage of the land
- channelize watercourses
- withdraw water for irrigation
- build towns and cities
- discharge pollutants into waterways.

7 Ecological Issues

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Highlights

- A watershed is a dynamic system, integrating geography, water flows, and biological communities that change with seasonal cycles. Streams and rivers, agricultural drains, lakes and ponds, riparian zones, and wetlands are elements of a watershed. Many animals (birds, mammals, amphibians, reptiles, insects, etc.) use aquatic habitats during at least one stage of their life history (e.g., for foraging, staging, breeding, and development of the young). For fish and many species of molluscs, crustaceans, and insects, water is their only habitat.
- As agriculture is situated within watersheds, its practices often interface with watershed components and always have some effect. This effect may involve altering wildlife habitat and its ability to support a diverse biological community. Agricultural and other rural development activities often lead to land clearing, drainage, and straightening channels, which can alter the physical nature of waterways. Irrigation infrastructure often provides new aquatic habitat. Excess nutrients cause eutrophication, which depletes oxygen. Nitrogen and some pesticides may be lethal or sub-lethal to aquatic organisms when concentrations exceed threshold levels.
- Numerous conservation projects have been undertaken in Canada to restore and improve riparian and aquatic habitat, including work on wetlands and agricultural drains. Enhancement measures not only benefit fish and wildlife but, in many cases, improve the quality of water used on the farm.
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- build towns and cities
- discharge pollutants into waterways.

Biodiversity in aquatic ecosystems

All living things need water for physiological processes. For many, water also makes up an important part, or the whole, of their habitat. Fish and other aquatic organisms, including many molluscs, crustaceans, insects, and plants, spend their entire lives in water. Some species live in water for one period of their development (amphibians and some terrestrial insects); others use water throughout their lives to meet some habitat needs.

For example,

- water settings are important to waterfowl (e.g., ducks and geese), colonial waterbirds (e.g., Great Blue Herons and terns), and shorebirds (e.g., plovers and snipes) for feeding, breeding, and protection against predators
- many turtles require water for feeding and shelter, and some species of snakes spend much of their time in or near the water
- muskrats, beavers, and other water mammals depend on aquatic ecosystems and the neighbouring vegetation for their food and lodgings
- waterways are important foraging ground for otherwise terrestrial species, such as raptors (e.g., bald eagles, ospreys), foxes, raccoons, and bears.

In short, water of suitable quality is one of the key supports of biodiversity—the wide array of life that exists on this planet. Ecosystems with great biodiversity are more stable than those whose species have been depleted. They are more resilient, better able to cope with perturbation, and have the genetic pool needed to allow species and whole communities to adapt over time to new ecological conditions.

S.F. Forsyth, Forsyth Consulting Essentials



A watershed is a complex and dynamic system, integrating geography, water flows, and biological communities that change with seasonal cycles. As agriculture and rural development are situated within watersheds, their practices often interface with watershed components and always have some effect, either positive or negative. Effects often include removing wildlife habitat or reducing its ability to support a diverse biological community (see Box). How greatly and widely these effects are felt is a function of how well agricultural practice and rural activities account for the way the watershed functions.

This chapter describes important watershed components and examines the potential effects of agriculture and other rural development on aquatic ecosystems (see Box opposite) in the context of these components. Because ecological studies are expensive and complex, fewer research results are available to illustrate this chapter than other chapters in the report.

Watercourses

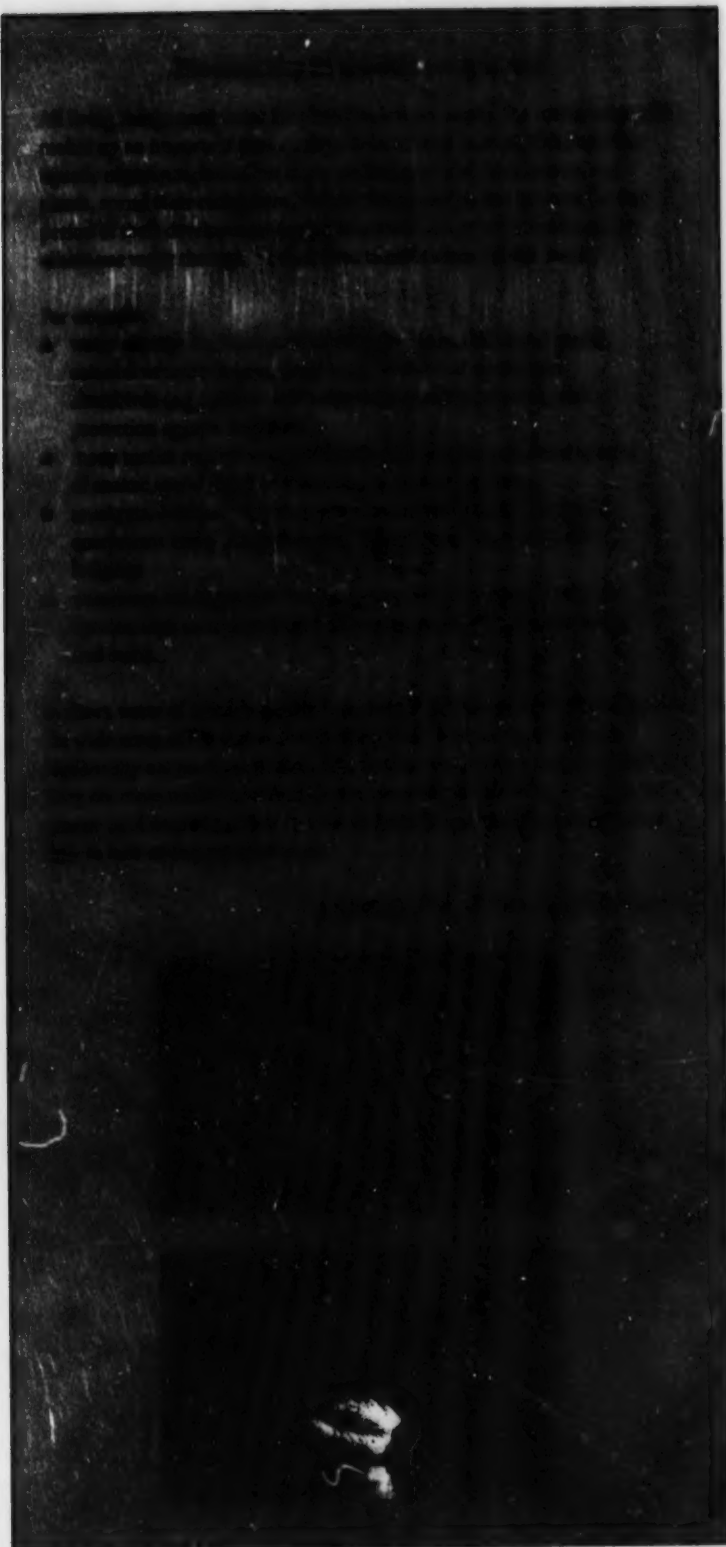
Watercourses running through agricultural land fall into two main categories:

- natural watercourses, such as creeks, streams, and rivers
- constructed watercourses, such as agricultural and municipal drains.

Water leaving farmland as surface runoff, tile drainage water, or leachate into groundwater enters watercourses. It then moves into receiving bodies, such as ponds and lakes, or larger watercourses that eventually reach the ocean. Thus, agricultural effects on these waterways (those related to both water quality and water quantity) build up as water makes its way through the watershed. Because agriculture is practised over such broad expanses of land over many months of the year, its potential to affect waterways and aquatic ecosystems is considerable.

Streams and rivers

Streams and rivers contain many habitat features that support a variety of water- and land-based ecosystems. Even small or temporary streams provide valuable habitat for fish and wildlife.



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Potential agricultural effects on aquatic ecosystems

Possible effects of agriculture and development

Sediments carried into water by soil erosion

Possible effects on aquatic ecosystems

- increase turbidity of the water
- reduce transmission of sunlight needed for photosynthesis
- interfere with animal behaviours dependent on sight (foraging, mating, and escape from predators)
- impede respiration (e.g., by gill abrasion in fish) and digestion
- reduce oxygen in the water
- cover bottom gravel and degrade spawning habitat
- cover eggs, which may suffocate or develop abnormally; fry may be unable to emerge from the buried gravel bed.

Nutrients from septic tanks, manure, and fertilizer carried into water

- promote overgrowth of algae and other aquatic plants (eutrophication), which
 - depletes oxygen in the water, sometimes suffocating aquatic animals
 - creates turbid conditions, restricting the amount of light
 - smothers many bottom-dwelling organisms and clogs spawning beds
 - reduces species diversity, as sensitive species are replaced with lower numbers of less desirable species.

Pesticides carried into water

Depending on the compounds involved, can

- cause direct kills of fish and other aquatic organisms, interrupting the food chain
- cause sub-lethal effects on reproduction, respiration, growth, and development, increasing an organism's vulnerability to other environmental stresses, such as disease or predation
- cause cancer, mutations, and fetal deformities
- inhibit photosynthesis in non-target plants
- can *bioaccumulate* in an organism's tissues and be *biomagnified* through the food chain (particularly some of the older pesticides no longer registered for use in Canada).

Clearing of trees and shrubs from shorelines

- destabilizes banks and promotes erosion
- increases sedimentation and turbidity
- reduces shade and increases water temperature; fish metabolism may be disrupted
- causes channels to widen and become more shallow.

Land clearing, constructing drainage ditches, straightening natural water channels

- increased flow creates an obstacle to upstream movement of fish and suspends more sediment in the water. Subsequent low flows strand fish upstream and dry out recently spawned eggs
- reduce baseflows

L.J. Gregorich, Gregorich Research

Aquatic components of a watershed



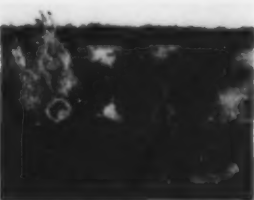
Stream



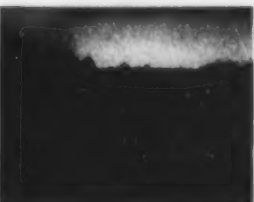
Agricultural drain



Farm pond



Riparian zone



Wetland

Permanent streams flow year round on the surface. Other streams can flow underground in places or dry up during hot summer or frozen winter months.

Streams naturally wind or meander. Meanders reduce the slope of the stream and slow down the moving water. They increase the amount of water the stream can hold, reducing the potential for downstream flooding. Side channels and oxbows, separate from the main channel, also increase the amount of water a stream can hold during high-water periods, as well as provide additional aquatic habitat.

Baseflow

Natural reservoirs, such as groundwater and wetlands, maintain a stream's baseflow. This flow is supplemented by overland flow and interflow (flow below ground level but above the water table). Watersheds with limited groundwater discharge often have headwater streams that dry up in midsummer and mainstem sections with extremely low flows after extended dry periods. Reductions in baseflow often follow the draining or filling in of wetlands. Wetlands store water from precipitation and surface flow, acting as recharge or delayed discharge areas. As wetlands are lost, insufficient groundwater may be available to provide baseflow in headwater streams. Increased competition for water between agricultural and municipal users and the threat of drier conditions under possible climate change scenarios (see Chapter 11) may further jeopardize groundwater and stream volume in the future.

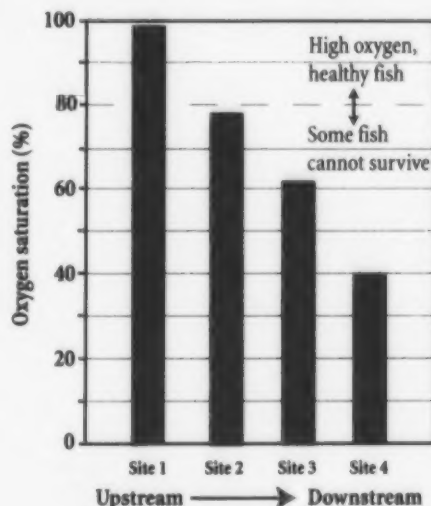
For example, the baseflow of some streams in southern Ontario has been affected by land clearing, drainage, wetland filling, and soil erosion so much that headwater streams have lost some of their natural ecological function. These changes have affected entire watersheds by increasing water temperatures, sediment and nutrient levels, and storm flows.

Water quality

Phosphorus and nitrogen are essential nutrients required by algae and aquatic vascular plants, the primary producers in aquatic ecosystems. In nutrient-limited systems, slight increases in the concentration of these nutrients stimulates greater productivity at all trophic levels. In most cases, aquatic systems are limited by phosphorus.

When slow-moving streams or rivers are over-enriched with nutrients, they become eutrophic (see Box, p. 77). Oxygen-consuming material is also added to surface waters in sewage and industrial discharges, and as organic material that is transported in surface runoff (e.g., leaves, manure). Eutrophication is more likely where nutrients come from several sources. Some reduction in dissolved oxygen occurs naturally as water flows downstream, but human activity has a marked effect.

For example, in a water quality study area in the Lower Fraser Valley in British Columbia, an upstream site flowing through forested land (Site 1, Fig. 7-1) had sufficient levels of dissolved oxygen to support several species of fish (98% saturation). Water quality was degraded as the water moved downstream through agricultural and urban land. At Site 2, water quality was slightly degraded by an urban area. After passing through many kilometres of agricultural land, the water at Site 3 was 63% saturated with dissolved oxygen, creating a barrier for salmon swimming upstream to spawn. At Site 4, at the mouth of a tributary that drains intensively farmed land, levels of dissolved oxygen were extremely low and some species of fish could not survive.



Source: Governments of Canada and British Columbia, 1997

Figure 7-1
Dissolved oxygen in a B.C. stream

A growing concern for stream and river quality is the entry of animal manure. Fish sometimes suffer from the high ammonia levels in water contaminated by manure. Over a longer period, bacteria consume available oxygen as the manure breaks down, and fish may suffocate. Nutrients in the manure also promote the growth of algae and aquatic vascular plants, which further deplete oxygen levels when they die and decompose.

In an ongoing Ontario study, manure ranks first among agents of fish kills (Fig. 7-2). From 1988 to 1996, 207 manure spills were reported, 175 of them in southwestern Ontario. Most spills took place while manure was being applied to fields, though 12% were caused by inadequate capacity or structural failure of manure storages. Of the 207 spills,

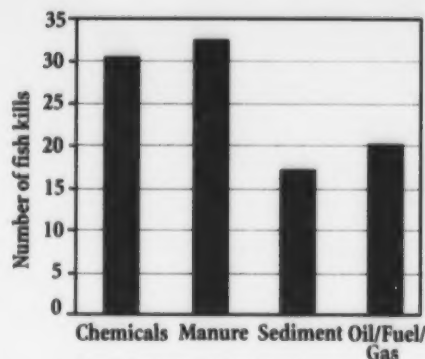
- 14% resulted in fish kills
- all but one were from liquid manure systems
- more than 40% resulted from liquid manure irrigation, the rest being associated with problems with equipment and manure transfer
- 60% involved contamination of tile drains.

Banks and beds

The roots of vegetation growing along streambanks hold the soil in place, limiting bank erosion. Streams bordered by shrubs and trees tend to be narrow and deep, whereas eroded streams become wider and shallower. Stream- and river-banks and beds can become degraded following a number of agricultural practices, such as plowing too close to the top of the streambank, allowing livestock access, and fording livestock or equipment.

Soil erosion adds to the sediment loading of streams and rivers and contributes substances that are attached to soil particles, such as nutrients, pesticides, and bacteria. High levels of sediments, nutrients, and pesticide contamination affect aquatic life in many ways (see Box, p. 77). Some fish depend on specific habitats to spawn. Sedimentation of cobble or gravel spawning beds can suffocate fish eggs and reduce spawning success.

Removal of vegetation along streams can alter the physical shape and stability of channels, leading



Source: Environment Canada, 1998

Figure 7-2
Causes of fish kills
reported in Ontario
1988–1997

to habitat degradation and increased costs for stream channel maintenance and remediation. Streams are being rehabilitated in many parts of the country to improve water quality and restore aquatic habitat (see Mink Creek case study, p. 80).

Agricultural drains

In the humid agricultural regions of Canada, fields are often artificially drained to improve conditions for cultivation (see Chapter 10). Drainage water generally flows first into excavated channels and then into natural watercourses. Artificial drainage can alter downstream hydrology, increase erosion and flooding, and degrade fish habitat and water quality. However, mitigation measures have been developed in some cases to improve these channels for fish and other aquatic life (see Box, p. 81).

*Installing lunkers to
rehabilitate a stream*



Case study

Effect on walleye reproduction of rehabilitating Mink Creek, Manitoba

Mink Creek is one of the tributary streams draining into Dauphin Lake, Man. Until 1950, the lake supported a large commercial and sport walleye fishery, but fish harvests then dropped by 90 to 95%. A major cause of the decline was extensive channelization of the tributary streams to improve agricultural drainage and reduce spring flooding. The stream channels were straightened and uniformly graded, which resulted in a shorter spring runoff period and eliminated most of the pool and riffle habitats used by walleye for spawning and incubation.

Before beginning rehabilitation of Mink Creek to restore walleye habitat, walleye spawning behaviour was observed for several years in the natural spawning reaches of a nearby river. It was found that walleye spawned near the crests of the riffles, behind emergent boulders on the riffle surface, and in large horizontal eddies in the upstream pool. Fertilized walleye eggs drifted into the riffle sections and settled into quiet water zones behind, and at the base of, large cobbles and boulders. Some eggs were carried through the riffle and deposited in the upper end of the downstream pool.

Rehabilitation of Mink Creek began in 1985 and involved a series of pools and riffles constructed in three experimental segments of the channelized stream. The success of walleye

spawning was followed for the next 6 years, comparing the riffle-pool habitats in the existing and rehabilitated sections of the channel. Spring discharges in the creek controlled the occurrence and location of walleye spawning activity. In 1989 and 1991, discharges were insufficient for walleyes to ascend the creek to spawn. Low spawning flows in 1988 limited walleye migration upstream, so higher egg densities were recorded in the rehabilitation zone, located in the lower reaches of the creek. In high discharge years (1987 and 1990), egg densities were higher in the upper channelized section. The viability of eggs from the channelized and rehabilitated sections was similar, with live eggs comprising an average 68 and 73%, respectively, of samples from all years.

Egg scour and egg drift were considered a serious problem, as viable eggs could settle and die in high siltation areas near Dauphin Lake. In all years, egg drift from the three habitat types (single riffle rehabilitation, double riffle rehabilitation, and existing channelization) was related to egg density and water discharge. Relative to egg densities, egg drift was one and a half times greater from the channelized section compared with the rehabilitated section (see Table below). The rehabilitated section appeared to trap and retain eggs that entered from the upstream channelized reach.

Aspects of walleye spawning success, Mink Creek, Man.

Measurement	Reach type	1986	1987	1988	1989	1990	1991
Mean egg density (catch / m ²)	Single riffle rehab	<1	1	20	0	29	0
	Double riffle rehab	-	4	7		41	
	Existing channelized	3	8	5		66	
Mean egg drift (catch / 24 h)	Single riffle rehab	19	<1	168	0	567	0
	Double riffle rehab	-	0	233		1251	
	Existing channelized	166	2	41		3701	
Mean larval drift density (catch / h per 100 m ³ water filtered)	Single riffle rehab	<1	5	1	0	11	0
	Double riffle rehab	-	42	2		No data	
	Existing channelized	<1	16	<1		No data	

Source: Newbury and Gaboury, 1993

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Managing agricultural drains to accommodate wildlife

Much of Ontario's farmland supports a network of surface and subsurface drains that carry excess water away from the fields into drainage ditches or natural waterways. Traditional design and management of these channels often results in poor water quality and degradation or loss of fish and wildlife habitat.

Under the Canada–Ontario Green Plan agriculture agreement, a 4-year project (1993–1997) called "Managing Agricultural Drains to Accommodate Wildlife" was undertaken to improve the water quality of agricultural drains and to expand wildlife habitat. The goal at each of four demonstration sites was to find practical and effective ways of incorporating the needs of fish and wildlife into drain design and maintenance, while maintaining or improving drainage outlets and reducing or minimizing costs.

One of the four sites was James Berry Municipal Drain in the region of Haldimand–Norfolk. This 6-kilometre drain empties into Big Creek Marsh, a Class 1 wetland, on Lake Erie. In 1992 the drain was improved to include 9-metre-wide continuous buffer strips, sediment basins, a retention pond with a water control structure, and a fish bypass around the structure. The drain is a warm-water fishery that supports spawning pike. This site provided the opportunity to evaluate the effectiveness of these measures, as well as various drain maintenance techniques.

The buffers were originally planted with exotic grasses, which in turn allowed for more than 11% of the cover to be taken over by noxious weeds. This share has declined to about 6% as native species have moved in. Grasshoppers are now abundant because of the natural food source, but no increased crop predation has been noticed. Large swarms of migrating Monarch butterflies use the area for roosting. Insects have attracted a growing number of birds to the buffers.

Water sampling through the stations along the drain has shown a significant drop in nitrate levels. The impoundment and the fishway, with adjustments to their design, support greater use and successful spawning by pike. The number of pike using the fishway increased from 2 in the first year to 68 in the last year of monitoring.

This project was managed by the Canadian Wildlife Service, Environment Canada. It was coordinated by the Ontario Soil and Crop Improvement Association.

P. Bryan-Pulham, Township of Norfolk

Two types of measures can be carried out to improve the function of agricultural drains:

- *Mitigation* measures, such as proper sloping and seeding of the banks, improve the performance of the drain by reducing erosion and sedimentation.
- *Enhancement* measures, such as adding pools and riffles to the channel, enhance the setting as fish and wildlife habitat.

Some rehabilitation features may benefit both drain function and wildlife habitat. For example, pools and riffles placed properly can improve the physical functioning of a drain, increasing its

stability and improving its ability to transport sediment and water during high flows while enhancing fish habitat. Buffer strips along the channel banks offer transitional habitat for wildlife and also trap sediments, resulting in lower costs and reduced frequency of cleaning out the drain. Buffer strips also ensure that farming activities, such as tillage and spraying, are carried out at a minimum distance away from the water.

Some old agricultural drains are no longer needed because of changes in land use patterns and agricultural practices. They were originally constructed to reduce the size of wetlands or





Two types of measures can be carried out to improve the function of agricultural drains:

- *Mitigation* measures, such as proper sloping and seeding of the banks, improve the performance of the drain by reducing erosion and sedimentation.
- *Enhancement* measures, such as adding pools and riffles to the channel, enhance the setting as fish and wildlife habitat.

Some rehabilitation features may benefit both drain function and wildlife habitat. For example, pools and riffles placed properly can improve the physical functioning of a drain, increasing its

stability and improving its ability to transport sediment and water during high flows while enhancing fish habitat. Buffer strips along the channel banks offer transitional habitat for wildlife and also trap sediments, resulting in lower costs and reduced frequency of cleaning out the drain. Buffer strips also ensure that farming activities, such as tillage and spraying, are carried out at a minimum distance away from the water.

Some old agricultural drains are no longer needed because of changes in land use patterns and agricultural practices. They were originally constructed to reduce the size of wetlands or

drain them for row cropping, or to drain land now considered marginal for agriculture. Today, such lands are often retired from farming, and the old drains remove water only from woodlots and swamps. This situation has presented an opportunity for land managers to investigate remedial plans that stop or decrease the flow of water from the land and return some of the natural function to local wetlands, in turn providing more wildlife habitat and increasing groundwater recharge.

Floodplains

Floodplains are the low-lying flat lands that border streams and rivers. When a watercourse reaches its capacity and overflows, such as during snowmelt and after storm events, the floodplain accommodates the excess. Floodplains play an important role in the watershed, by

- receiving sediments that settle out of flood waters
- absorbing and storing water during floods and rainfall; this water supplies plants, including agricultural crops, during dry summer months
- providing large expanses of wildlife habitat that supports diverse plant and animal communities
- providing low velocity refuge areas for fish during floods.

When drainage is improved to allow water to flow away rapidly, the floodplain has less opportunity to soak up water. The resulting lower water table and groundwater inputs reduce the amount of water that is available during dry summer months to both natural and agricultural communities of plants and animals. Urban and residential development in floodplains involves the creation of impervious cover and the use of measures to protect developed areas from flooding. These features reduce the natural flood plain area and contribute to greater flow, erosion, and damage downstream (see Chapter 10).

Lakes and ponds

Lakes and ponds provide a diversity of aquatic habitat. The *littoral zone*—that portion where sunlight reaches the bottom, usually in shallow areas near the shore (up to 5 metres deep,

depending on turbidity)—is the most productive part of lakes and ponds. This diverse habitat is home to a variety of waterfowl and shorebirds, fish, amphibians, reptiles, mammals, and plants. Most fish, cold- and warm-water species alike, rely on the littoral zone for their early life stage requirements (e.g., during the spawning, larval, and juvenile stages), although their littoral habitat preferences vary by species.

Nutrient enrichment of lake and pond water can promote eutrophication, as it does in streams and rivers. Much has been reported on the nutrient enrichment and eutrophication of the Great Lakes, particularly Lake Erie, during the 1960s and 1970s. As pollution controls were put into place, the subsequent decline in phosphorus loading and increase in the nitrogen:phosphorus ratio in Lake Erie led to a reduction in the total phytoplankton biomass of 40% by the late 1970s and 65% by the mid-1980s in the western basin. Algal species composition shifted in near-shore waters, and the abundance and biomass of nuisance species decreased by 85% by the mid-1980s. During this period, fish species composition also changed, partly as a result of changes in nutrient status and partly because of species introductions. In southern Lake Michigan, densities of the major *benthic invertebrates* declined dramatically in near-shore waters between 1980 and 1993, mainly as the result of planned reductions in nutrient loading and a general decline in productivity.

Nutrient enrichment continues to be a problem in some ponds and lakes receiving nutrients from farmland. In 1992, researchers studied the effects of fertilizers on the structure and function of the microbial community of Redberry Lake, a saline, oligotrophic lake with an area of 45 square kilometres in south-central Saskatchewan. Except for a narrow buffer zone of brush, aspen forest, and grassland, this lake is totally surrounded by cultivated land. Because the lake is located in a hydrologically closed basin, any herbicides or nutrients entering the system as a result of agricultural practices will stay in the basin. This laboratory study of microcosms showed that adding both nitrogen and phosphorus caused the phytoplankton biomass to increase and also stimulated bacteria to grow and reproduce.

Excess nutrients may have toxic effects on organisms (Table 7-1). Laboratory studies have

shown that lethal and sub-lethal effects in several common frog species are detected at nitrate concentrations above 2.5 milligrams per litre. Sub-lethal effects include altered growth and development, potentially resulting in late maturation and emergence from the water before development is complete. This in turn may limit the ability of amphibians to move in the land environment, making them more vulnerable to predators and dessication. Recent studies in the Great Lakes basin have shown that nitrate concentrations in about 19% of surface water samples are high enough to cause developmental anomalies, and 3% are high enough to kill amphibians in laboratory experiments. The spring use of nitrogen fertilizer and the reproduction period of amphibians correspond, which creates a vulnerable period.

Excessive nutrients can also promote the growth of potentially toxic organisms. In inland settings, toxic algae called cyanobacteria grow in warm, stratified surface waters that are enriched with phosphorus and low in nitrogen. Toxic cyanobacteria produce *neurotoxins* and *hepatotoxins* that have been fatal to fish and livestock when ingested. In coastal waters, nutrient enrichment can promote the growth of certain algae that produce toxins, which can accumulate in shellfish. The shellfish are only marginally affected, but the toxins can be acutely toxic to humans. A 1987 case of food poisoning from eating contaminated mussels was linked to a toxin produced by marine algae that were stimulated by nutrients, particularly nitrate, from a river in an agricultural district of Prince Edward Island. It is believed the algal bloom resulted from nitrate runoff during an intensely wet fall following a long dry summer.

Pesticides that enter ponds and lakes have the potential to disrupt the metabolism of organisms at all levels of the food chain in the aquatic system. A study of the toxic effects of 14 herbicides and 2 fungicides on plankton communities from Jack's Lake, Ont., found that herbicides that specifically inhibit photosynthesis were most toxic to phytoplankton's uptake of carbon. Those that affect other cellular metabolic processes had a greater effect on the uptake of phosphorus and ammonium. Table 7-2 shows the toxicity of some of these pesticides to phytoplankton related to the uptake of these three substances.

Table 7-1
Toxicity of nitrate to amphibians and their prey and predators

Amphibian	Life stage	Observed effect	Nitrate concentration (mg/L)
Western chorus frog	Tadpole	50% mortality after 96 h Developmental	17 2.5-10
Northern leopard frog	Tadpole	50% mortality after 96 h Developmental	22.6 2.5-10
Green frog	Tadpole	50% mortality after 96 h Developmental	32.4 2.5-10
American frog	Tadpole	50% mortality after 96 h	13.6 39.3 (two studi
Caddis fly	Larvae	50% mortality after 96 h	113.5
Rainbow trout	Egg and fry	46% mortality	2.3
Cutthroat trout	Egg and fry	41% mortality	4.5

Source: Rouse et al., 1999

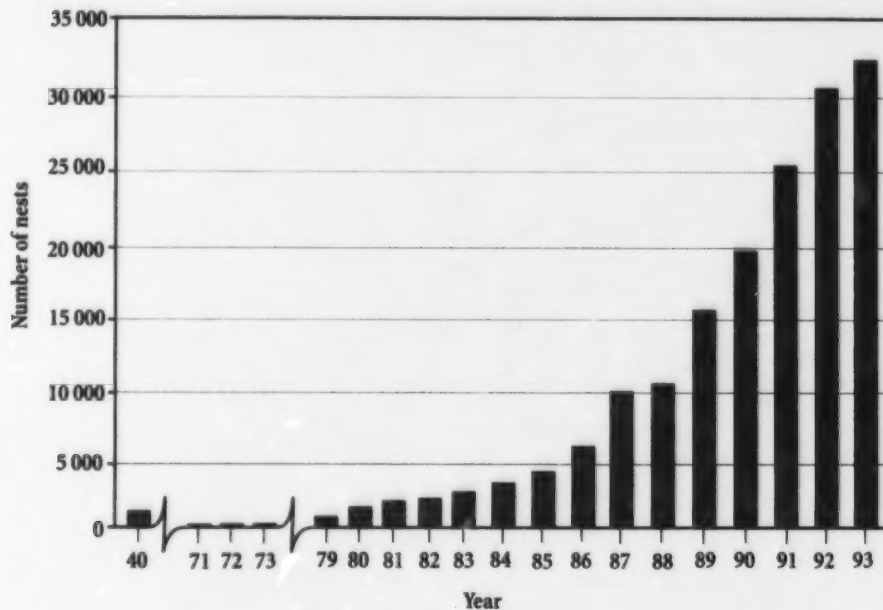
Table 7-2
Concentration (mg/L) of selected pesticides sufficient to reduce by 50% the rate of carbon, phosphate, and ammonium uptake in plankton

Herbicide	Carbon	Phosphate	Ammonium
Atrazine	0.10	14	>33
Simazine	0.13	>33	NA
Prometryne	0.022	>33	>33
Diuron	0.0079	>33	25
Dinoseb	1.0	12	5.0
2,4-D	>33	>33	>33
Trifluralin	1.02	>33	2.2

Source: Brown and Lean, 1994

A 1992 laboratory study of the effects of triallate (a herbicide commonly used on the Prairies to control wild oats and other broadleaf weeds) on the microbial community of Redberry Lake, Sask., found that phytoplankton biomass declined substantially at triallate concentrations greater than 1000 micrograms per litre. The negative effects of this herbicide on phytoplankton have drawn the caution that it not be applied near wetlands. In contrast, triallate had no apparent negative effects on bacteria at any concentration and stimulated the production, metabolism, and numbers of bacteria if nitrogen and phosphorus were also added.

Figure 7-3
Double-crested cormorant
population in
the Great Lakes



Adapted from Environment Canada, 2000

Organochlorine pesticides contaminating the Great Lakes during the 1960s and 1970s were linked to eggshell thinning and subsequent reproductive failure in several bird species, including the Bald Eagle. As the use of these pesticides has been discontinued, many waterbird populations have recovered dramatically, none more so than that of the Double-Crested Cormorant (Fig. 7-3).

Although the highly persistent organochlorine pesticides are generally no longer used in Canada (except endosulfan), they are still widely detected in Canadian lakes. Their presence probably results from long-range transport from countries where they are still used, after which they are deposited here in precipitation. The long half-lives of some of these pesticides (e.g., 15 years for DDT) may also explain their continued presence. Concentrations of these pesticides vary both geographically and over time. In a 1986 study, organochlorines were detected in 33 southern Ontario lakes. Higher concentrations of organochlorines were found in plankton from lakes in which the total plankton biomass was lower, demonstrating a biomass dilution effect—the greater the biomass to absorb the contaminants, the lower the concentration of contaminants in that biomass, although the total quantity of contaminants remains the same.

Riparian zones

Riparian zones are vegetated zones beside rivers, creeks, drainage ditches, lakes, sloughs, wetlands, canals, and springs, and in *coulees*. Among their benefits, they

- help to reduce flooding (*flood attenuation*) by storing water during high water events
- serve as areas for groundwater recharge and discharge
- retain nutrients and curb their movement into waterways
- reduce sedimentation and help to conserve topsoil.

Riparian zones with trees and shrubs provide shading to streams and reduce stream temperatures.

Available water and sloping land in riparian zones create conditions that support plants and animals different from those inhabiting neighbouring land, including farmland. These zones provide animals with a source of water, food, shelter from adverse conditions, and safe sites to raise offspring and avoid predators. Riparian ecozones are among the world's most productive and richest in biodiversity. In the Canadian Prairies, for example, studies have shown that most wildlife species spend at least one stage of their life cycle in a riparian ecosystem. Riparian zones

also provide travel corridors for some species as they move from one area to another.

As farms have expanded and farming has become more intensive, land has been cultivated closer to the edge of watercourses, resulting in much riparian area being lost over the years. Besides reducing terrestrial wildlife habitat, this loss has reduced the buffer between farmland and waterways. Restoring riparian zones is a key component of many plans to rehabilitate watercourses (see Purpleville Creek case study, p. 86).

Wetlands

Wetlands are areas saturated with water for long enough to significantly alter soils and vegetation and promote aquatic processes. The five main types of wetlands—bogs, fens, swamps, marshes, and shallow water—are characterized by

- a seasonal or permanent covering of shallow water
- a water table at or near the surface for most of the growing season
- saturated organic soils, or *peat*, the productivity of which depends on the nutrient status and the pH of the site
- water-loving plants, such as cattails, rushes, reeds, sedges, dogwood, willows, and cedars.

Canada, with more than 14% of its area as wetlands, accounts for about 24% of all the world's wetlands. The loss of wetlands in Canada accelerated as land was converted to agriculture. Many wetlands have been drained for cultivation or other forms of development. In southern Canada, more than half the original wetlands have been drained, of which about 85% have been drained as a result of agriculture.

Benefits of wetlands

Wetlands offer many environmental benefits, by

- providing habitat for wildlife
- improving water quality by serving as biological filters and mechanical settling and filtering ponds, which help to remove impurities from the water
- recharging groundwater
- augmenting low flow in watercourses



Planting trees in a riparian zone

- buffering against drought
- reducing the risk and damage of flooding by storing large volumes of water during heavy rainfall, rapid thaws, or runoff events
- stabilizing shorelines.

Wetlands also provide recreational, educational, and economic opportunities, through such uses as canoeing, fishing, hunting, ecotourism, school trips, and the harvesting of resources (e.g., wild rice).

Canadian wetlands are especially noted for supporting North America's waterfowl species. However, other avian groups, including songbirds, shorebirds, and raptors, use wetlands for nesting habitat, protective cover, or sources of food. Wetlands are equally important to non-avian wildlife. For example, wetlands

- provide essential breeding habitat for many amphibian and reptile species
- are prime locations, associated with lakes or rivers, for a large number of freshwater fish seeking shallow waters for cover, spawning, and nurseries
- serve as primary habitat to some mammals adapted to aquatic conditions (e.g., beavers and muskrats), and secondary habitat for other upland species that occasionally use these areas to escape predators, reproduce, or forage (e.g., raccoons, shrews, and moose).

This considerable biodiversity is common within wetlands because of the unique meshing of water and land. These transition zones are highly productive, because they provide breeding and

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Case study

Rehabilitation of Purpleville Creek, Ontario

The Purpleville Creek Rehabilitation Project began in 1995 in an effort to rehabilitate one of the last remaining brook trout streams in the Toronto area. Purpleville Creek is a small (16 kilometres) cold-water tributary of the East Humber River. Livestock grazing and urban development have had a detrimental effect on the riparian corridor. Excessive bank erosion from trampling, grazing along stream banks, and the runoff of manure into the creek were seen as the major causes of poor water quality and elevated water temperatures. Also, poor road culvert design had resulted in *habitat fragmentation* (the breaking up of habitat into smaller areas as a result of humans modifying or converting the landscape for their own purposes).

The presence of brook trout and the redbreasted dace in Purpleville Creek affirmed the importance of protecting the creek's habitat. Both fish are particularly sensitive to riparian habitat degradation. Siltation, removal of natural edge cover, channelization, and pollution from agricultural, domestic, and industrial sources reduce suitable habitat and food sources for these species.

The objectives of the project were to improve water quality and fish community diversity, as well as to increase brook trout and redbreasted dace populations, through

- promoting public awareness and educational opportunities through volunteer workdays

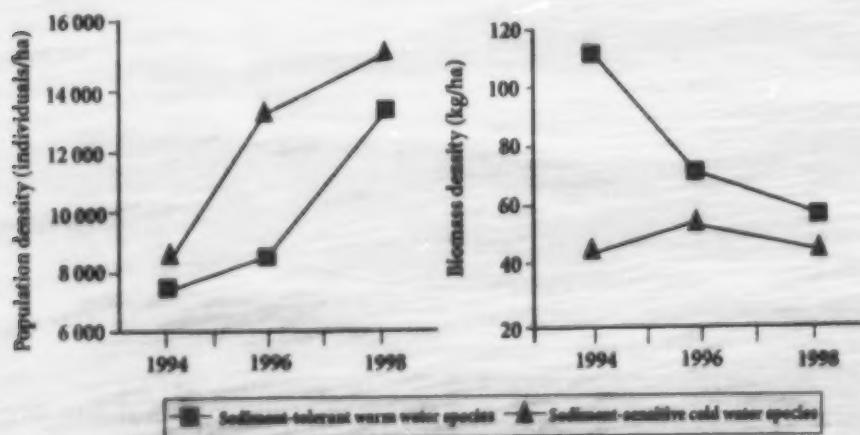
- fencing stream sides, creating habitat through soil bioengineering, planting trees and shrubs, and installing in-stream habitat structures.

Trends in the fish community in the subwatershed were monitored.

By the fall of 1999, about 2000 hours of labour had been provided by project participants and 4.5 kilometres of riparian habitat had been protected and rehabilitated. Activities included

- placing more than 40 habitat structures (e.g., log jams, lunkers, and native materials)
- removing channel obstructions and garbage
- completing a culvert fishway
- installing 1800 metres of cattle fencing and three cattle-tractor creek crossings
- providing baseline monitoring of temperature and fisheries biomass.

Assessment of the fish community, divided into sediment-sensitive cold water (SSC) and sediment-tolerant warm water (STW) *guilds* showed a net increase in the abundance and biomass of the SSC group over a 6-year period (see two Graphs below). Further work on the creek will involve maintaining existing structures, installing more habitat structures and cattle fencing, and continuing to promote awareness and educational opportunities.



M.G. Heaton and V. Samaras, Ontario Ministry of Natural Resources

feeding grounds for thousands of invertebrate species at the base of food chains. Directly or indirectly, these invertebrates contribute to the critical habitat that supports 23 species of birds, mammals, amphibians, and reptiles, as well as numerous other fish and plant species, currently deemed endangered or threatened in Canada.

By adding to the habitat diversity of the landscape and accommodating species that use multiple habitats, wetlands also contribute significantly to the biological diversity beyond their borders. For example, deer or moose commonly use a hardwood forest in winter when thick conifers, commonly associated with swamps, are nearby to provide thermal cover.

Waterfowl habitat

Waterfowl, such as ducks and geese, depend on wetlands for breeding, feeding, and protection. So important are these habitats that in the Prairies their availability determines the abundance of many waterfowl species. Studies show that populations of pintail ducks fluctuate as the number of wetlands changes with wet and dry cycles. The Prairies are used by

- 37% of North America's ducks and 50% of Canada geese for breeding
- 99% of white fronted geese, 83% of lesser snow geese, and 100% of Ross' geese for staging during migration.

Waterfowl are also affected by poor water quality. Sedimentation and eutrophication of waterways have been found to reduce the number of aquatic prey insects and also limit the visibility for diving ducks. Pesticides can also alter the availability of food, and herbicides can reduce necessary cover. Besides the potential effects on habitat, some pesticides have poisoned adults birds and their offspring directly when ingested in sufficient quantities and may cause death or reduce their chances for survival by affecting them in less visible ways (e.g., disrupting their feeding, breeding, or parental care behaviour).

Many farmers now employ management practices that encourage the presence of waterfowl on their land. These practices include

- growing forages on marginal land where waterfowl can nest
- delaying cutting until the young have left nest sites

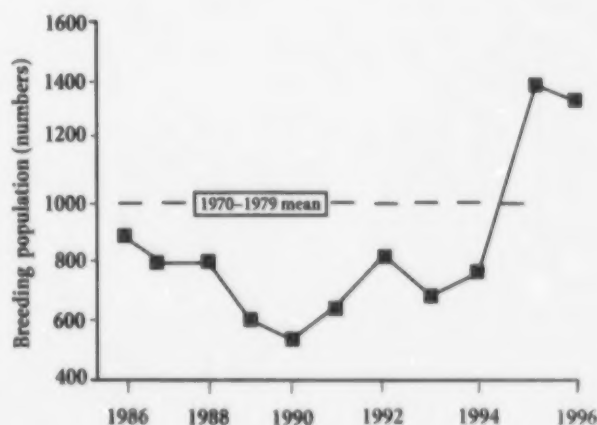
North American Waterfowl Management Plan

The North American Waterfowl Management Plan (NAWMP) is the most ambitious continental wildlife conservation initiative ever attempted. It seeks to restore waterfowl populations in Canada, the United States, and Mexico to levels recorded during the 1970s, a benchmark decade for conserving waterfowl through habitat securement and management. In 1998, partners in the plan broadened the mandate to include other bird species. Most projects under NAWMP typically include other species, such as fish and amphibians, found within the project area.

This completely voluntary program demonstrates how thousands of partners representing diverse interests can conserve habitat and allow traditional economic activities to continue. In its 13 years of operation, more than 2 million hectares of wetland ecosystems have been conserved across the continent, and most waterfowl populations are showing signs of recovery. Many institutional structures have been modified over the years by NAWMP partners, including wetland policy, the *Income Tax Act*, municipal tax assessments, conservation easement legislation, and joint agriculture-wildlife program initiatives.

Expanding the vision of the plan over the next 5 years depends on the interest, commitment, expertise, and resources of volunteer partners. The strength and future of NAWMP is its vision of biologically based planning that uses a landscape approach to managing habitat and seeks to balance conservation and socioeconomic objectives through cooperation with government, nongovernment, corporate, community, and individual partners.

K. W. Cox, North American Wetlands Conservation Council (Canada)



Adapted from McRae et al., 2000

Diving duck population in North America

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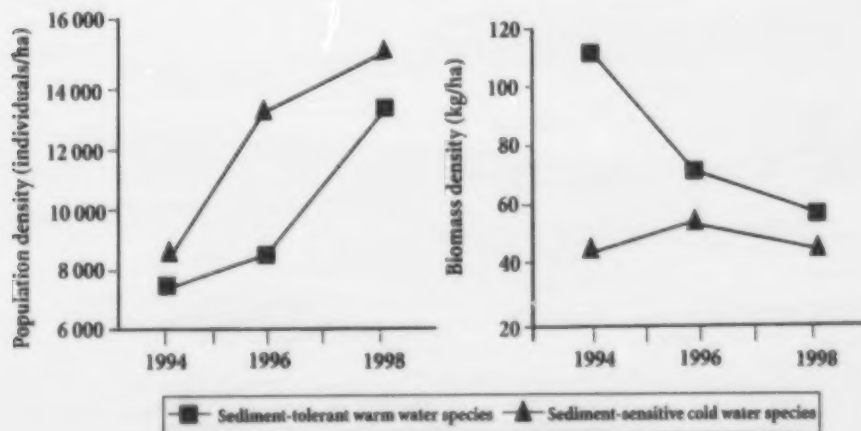
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M.G. Heaton and V. Samaras, Ontario Ministry of Natural Resources

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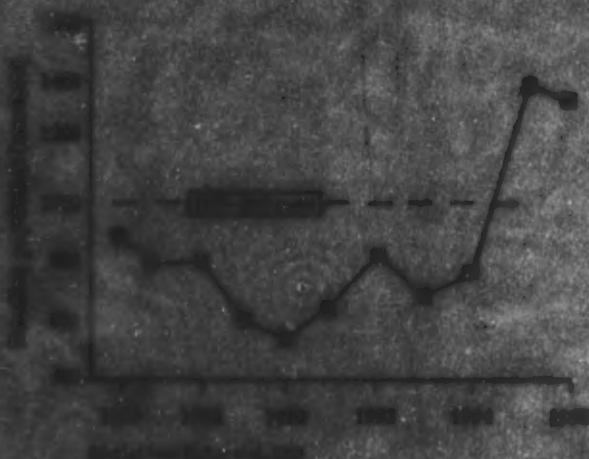
Wetland Conservation and Management Plan

The Wetland Conservation and Management Plan (Wetland Plan) was developed by the Canadian Wildlife Service (CWS) in 1990. It sets out the objectives and priorities for the protection and management of wetlands in Canada, the United States and Mexico. The plan was developed in response to the 1990s, a decade of concern for conserving wetlands and their resources. The plan is a framework for developing and implementing wetland conservation and management plans. It is a framework for developing and implementing wetland conservation and management plans. It is a framework for developing and implementing wetland conservation and management plans.

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E. W. Carr, North American Wetlands Conservation Centre, Toronto



Source: Canadian Wildlife Service, 1990

- modifying grazing patterns to keep some paddocks free of livestock until use by waterfowl is finished
- using land management practices that promote better water quality.

In the Prairies, the drop in waterfowl populations resulting from the loss of wetlands is now being reversed to some degree under programs such as the North American Waterfowl Management Plan (see Box, p. 87) and similar projects run by groups such as Ducks Unlimited. With the cooperation of farmers, these and other conservation groups are restoring and re-establishing wetlands, and adding features such as small dams, nesting boxes, and vegetation to improve the habitat potential. Wetlands provide staging sites for migrating waterfowl, as well as nest sites. Farmers can use the water for irrigation or watering livestock (using troughs or nospumps some distance away from the wetland area). Restored wetlands can provide a year-round source of water where there once may have been only a seasonal stream.

Constructed wetlands

Constructed wetlands are being used on several farms in eastern Canada to treat manure runoff and milkhouse waste. Studies have shown that fecal coliform counts in barnyard runoff directed through an artificial wetland may drop by as much as 99%. The removal of solids, nutrients, detergents, and bacteria by artificial wetlands can improve the quality of wastewater before it is discharged into streams and coastal settings, thereby improving fish habitat and helping to lower bacterial contamination in shellfish harvesting areas.

Where constructed wetlands are used as tertiary treatment for wastewater that does not contain materials toxic to wildlife (e.g., heavy metals), they can provide high-quality wildlife habitat. For example, the Eastern Habitat Joint Venture (a partnership of provincial and federal governments, Ducks Unlimited Canada, and Wildlife Habitat Canada to deliver the North American Wildlife Management Plan in eastern Canada) has developed several artificial wetlands in the Atlantic provinces to help clean domestic wastewater and agricultural runoff from manure storage and feedlots. Water is first held in a series of two settlement ponds to remove solids. It then

enters a third or tertiary wetland complex, where natural processes work to break down bacteria and recycle the nutrients before the wastewater is discharged into receiving waters. These constructed wetlands use the nutrients in the wastewater to support a rich and diverse community of plants and animals. Although this system has been used successfully to treat wastewater and create wildlife habitat, natural wetlands should not be used as water treatment facilities.

Integrated ecosystems

Treating aquatic and woodland habitats and the surrounding pasture and other agricultural land as an integrated ecosystem presents unique opportunities to provide habitat for birds and other species while promoting sustainable agriculture. For example, Ontario's Wetlands-Woodlands-Wildlife (W3) program focused on a number of watersheds between 1993 and 1997. The program included incentives to adopt practices that protect, create, or enhance fish and wildlife habitats, such as

- introducing delayed grazing
- restricting cattle access to the stream (see Box, p. 89)
- using alternative water systems, such as solar-powered pumps and remote troughs
- planting berry shrubs
- signing corridor agreements
- planting lure crops
- redesigning stream crossings to protect habitat
- planting grass strips along streams.

Nearly all farmland offers at least some habitat opportunities for wildlife. Unworked land, including wetlands and woodlands, provides habitat of the best quality. Agriculture and Agri-Food Canada has recently undertaken an assessment of trends in the availability of wildlife habitat on farmland (see Box, p. 90). This assessment showed that habitat is especially at risk in the areas of intensive agricultural production found in the Pacific Maritime Ecozone in British Columbia and the Mixedwood Plain Ecozone in Ontario and Quebec.



Esthetic appeal of water in the rural landscape

Keeping cattle out of wetlands and streams

When cattle have access to water bodies the most significant direct impacts are often damage to stream-side vegetation and stream bank stability by grazing and trampling. When this happens

- stream-side vegetation is no longer able to trap sediments and nutrients from surface waters that flow overland to water bodies
- the banks themselves erode, and the resulting sedimentation degrades aquatic habitat for invertebrates and fish spawning and accelerates eutrophication
- the loss of stream-side vegetation means less shade and higher stream temperatures, which negatively affects many fish species and promotes further growth of undesirable algae and aquatic macrophytes

Recent studies in Alberta also suggest that cattle may gain more weight when they drink from fenced-off water supplies. Researchers attributed this difference to the improved health resulting from drinking clean water instead of silty, soiled water, and the greater ease of drinking from a fenced-off supply compared with wading in a dugout or shoreline mud.

T.J.V. Sopuck, Manitoba Heritage Habitat Commission

A large area of wetland and a cold-water tributary of Cold Creek cut through a 100-head cow-calf and finishing operation on about 80 hectares in east-central Ontario. The cows used to water in a muddy depression in the wetlands. Now three-strand high-tensile electric fencing has been installed around the perimeter of the wetland and an area of wooded swamp to reduce cattle access. A battery-operated water system, called a Heissler pump, was installed to water the cattle. Cattle now receive better-quality water, with reduced risk of water-borne disease and parasites and loss of cattle because of miring.

Another 80-head cow-calf operation has about 32 hectares of pasture, 2 hectares of woodland, and 19 hectares of riparian wetland along the Snake River in eastern Ontario. A 240-metre section of the river and about 2.4 hectares of riparian habitat have been fenced off with three-strand electric fencing to prevent cattle access. An impoundment created in a natural depression catches runoff and supplies water to a gravity-fed trough on a concrete pad. The newly created pond and adjacent habitat have also been fenced to prevent cattle access. The retired riparian area has been enhanced for wildlife by planting trees and shrubs. The cattle now benefit from having a central watering facility with better footing. This improvement has also resulted in better pasture use and grazing.

The Cold Creek and Snake River projects were Wetlands/Woodlands/Wildlife (W3) projects carried out in cooperation between the Ontario Federation of Hunters and Anglers, the Ontario Hunters Association, and local groups. Completed in 1997, W3 was managed by the Canadian Wildlife Service, Environment Canada, in cooperation with the Ontario Ministry of Agriculture, Food and Rural Affairs and funded mainly under the Canada-Ontario Green Plan agriculture agreement.



Fencing to keep cattle out of a stream

Ontario Cattlemen's Association, Guelph, Ont.

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Water in the landscape

The importance of water to the esthetic appeal of rural landscapes should not be underestimated. People are attracted to the serene view of a stream wandering through farmland or a trout pond nestled in the woods. Alterations to the appearance of rural waterways, either in their

course or the water itself, may detract from this landscape appeal.

Canada, with its vast tracts of rural countryside and abundance of natural water bodies, has tended to undervalue the esthetic aspect of the environment. The developed and relatively crowded conditions in Europe have resulted in a high value being given to rural landscapes, as places of beauty and refuge for city people. With their growing interest in ecotourism and rural pastimes, Canadians are also beginning to realize that the beauty of our rural landscapes, including their waterways, is something we shouldn't take for granted.

Conclusion

Agricultural activity is becoming more and more intensive, and there is increasing residential and industrial development in rural areas. There are many opportunities to improve their coexistence with natural ecosystems, and wildlife in particular. Besides the many farm management practices to protect and improve water quality suggested in Chapter 8, continued interest is needed in preserving wildlife habitat on farmland, particularly in areas of intensive agriculture. A variety of practical ways exist to restore or create wetlands, riparian areas, and aquatic habitats. Individual land owners can undertake some of these measures, but others require the cooperation of a group of people. In all cases, the changes begin with a stewardship attitude that recognizes the value of biodiversity, healthy ecosystems, and the availability of clean water.

Farmers and rural residents often give their appreciation for nature and the natural environment as an important reason for choosing agriculture as a lifestyle and the country as a place to live and raise their children. Living in harmony with natural ecosystems while operating economically viable farms and businesses is essential to preserving the rural environment that is so valued by rural and urban dwellers alike.

Wildlife habitat on Canada's agricultural land

Loss and alteration of habitat is the leading cause of the depletion of the earth's wildlife resources, and thus of biodiversity. Agriculture has affected both the quantity and quality of wildlife habitat in Canada. At the same time, some wildlife species are able to thrive where native habitat has been replaced by agricultural habitat, and farmland often more benefits to wildlife than more developed areas, such as towns and cities.

In an attempt to assess trends in the value of farmland as wildlife habitat, an indicator of the Availability of Wildlife Habitat on Farmland has been developed as one of a suite of national agri-environmental indicators. The indicator was used to identify which habitat types in the agricultural landscape support the most wildlife use and whether associated habitat areas increased, decreased, or remained constant between 1981 and 1996. The habitat types correspond to the five main land use categories defined in the 1996 Census of Agriculture, which are Cropland, Summerfallow, Bare or Seeded Pasture, Natural Land for Pasture, and All Other Land.

All Other Land proved to be the most valuable wildlife habitat type of the five. This habitat category includes wetland and aquatic habitat, such as bogs, marshes, and sloughs. Thus, trends in the area of All Other Land in the seven terrestrial ecoregions in which agriculture is practiced (see Table below) give a general idea of trends in the area of wetlands and aquatic habitats on Canada's agricultural land.

Region	Area of All Other Land in 1996 (1000s ha)	Percent change in area of All Other Land between 1981 and 1996	Number of habitat use units* supported by All Other Land
Pacific Maritime	19	-21	1705
Montane Cordillera	174	constant	2271
Boarder Plains	1561	0	1740
Prairies	1006	16	1014
Great Shield	320	constant	2009
Wooded Plains	984	-15	2191
Atlantic Maritime	63	15	1003

*A habitat use unit is a measure of the variety of individual ways in which the habitat is used by wildlife. (e.g., Mallard nesting and Mallard feeding count as two habitat uses).

Source: McRae et al., 2000

8. Protecting Water Quality

C. Bernard, G.L. Fairchild, L.J. Gregorich, M.J. Goss, D.B. Harker, P. Lafrance, B. McConkey, J.A. MacLeod, T.W. Van der Gulik, L.J.P. van Vliet, and A. Weersink

...of agricultural practices, including the use of fertilizers, pesticides, and herbicides, and the management of manure and crop residues. Appropriate land management practices include crop rotations, conservation tillage, and cover crops.

- **Land management includes adopting integrated pest management and nutrient management plans that take into account the nutrient content of manure and crop residues. Appropriate land management practices include crop rotations, conservation tillage, and cover crops.**
- **The agriculture industry is supporting the efforts of farmers to become more environmentally sustainable by working with government and other agencies to provide guidelines and codes that define acceptable agricultural practice, encourage the adoption of environmental farm plans, and, in some cases, offer peer advice on resolving nuisance or pollution complaints.**
- **Water quality problems are often evident in specific watersheds and are felt by whole communities. They must be dealt with at this geographical scale, beginning with the creation of a coalition that represents all interests and is ideally motivated and led by farmers and other landowners. Several examples of successful endeavours of this kind exist in Canada.**
- **Government responsibility for protecting water quality related to agriculture includes education and training, policy and programs with environmental goals that target high-risk areas (e.g., areas of intensive crop and livestock production), and regulatory controls.**

Introduction

Protecting water quality is a concern for all Canadians. Farmers are the first to be affected by pollution from farm-derived substances. It is in their best interest to take steps to protect water quality, rethinking the way resources are used and balancing production goals with the need for environmental quality. The benefits they reap by reducing the pollution resulting from agriculture may include greater efficiency and productivity, lower production costs, and improved health for

their families and animals. Agricultural industry groups can support individual farmers in their efforts to protect water quality through means such as education, technology transfer, and assistance in identifying and carrying out appropriate management practices.

Protecting water quality often becomes a community concern, bringing the interests of farmers together with those of many other water

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All Other Land proved to be the most valuable wildlife habitat type of the five. This habitat category includes wetland and aquatic habitat, such as bogs, marshes, and sloughs. Thus, trends in the area of All Other Land in the seven terrestrial ecozones in which agriculture is practised (see Table below) give a general idea of trends in the area of wetlands and aquatic habitats on Canada's agricultural land.

Ecozone	Area of All Other Land in 1996 (1000s ha)	Percent change in area of All Other Land between 1981 and 1996	Number of habitat-use units* supported by All Other Land
Pacific Maritime	19	-21	1755
Montane Cordillera	194	constant	2271
Boreal Plains	1561	8	1740
Prairies	1986	16	1814
Boreal Shield	350	constant	2043
Mixedwood Plains	594	-19	2191
Atlantic Maritime	603	13	1683

*A habitat-use unit is a measure of the variety of individual ways in which the habitat is used by wildlife (e.g., Mallard nesting and Mallard feeding count as two habitat uses).

Source: McRaet *et al.*, 2000

Conclusion

Agricultural activity is becoming more and more intensive, and there is increasing residential and industrial development in rural areas. There are many opportunities to improve their coexistence with natural ecosystems, and wildlife in particular. Besides the many farm management practices to protect and improve water quality suggested in Chapter 8, continued interest is needed in preserving wildlife habitat on farmland, particularly in areas of intensive agriculture. A variety of practical ways exist to restore or create wetlands, riparian areas, and aquatic habitats. Individual land owners can undertake some of these measures, but others require the cooperation of a group of people. In all cases, the changes begin with a stewardship attitude that recognizes the value of biodiversity, healthy ecosystems, and the availability of clean water.

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8. Protecting Water Quality

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Highlights

- Protecting water quality is the responsibility of individuals, interest groups, and communities, but the key to the environmental sustainability of agriculture is farmers, who have the most control over farm management practices that potentially contribute to declining water quality.
- Farmers can help to improve water quality in three main ways: controlling the processes that move soil and agricultural inputs into water (e.g., erosion, runoff, and drainage), improving the way in which agricultural inputs (e.g., fertilizers, manure, and pesticides) and waste are managed, and making use of buffer zones and shelterbelts.
- Input management includes adopting integrated pest management and nutrient management plans that take into account the nutrient content of manure and crop residues. Appropriate land management practices include crop rotations, conservation tillage, and cover crops.
- The agriculture industry is supporting the efforts of farmers to become more environmentally sustainable by working with government and other agencies to provide guidelines and codes that define acceptable agricultural practice, encourage the adoption of environmental farm plans, and, in some cases, offer peer advice on resolving nuisance or pollution complaints.
- Water quality problems are often evident in specific watersheds and are felt by whole communities. They must be dealt with at this geographical scale, beginning with the creation of a coalition that represents all interests and is ideally motivated and led by farmers and other landowners. Several examples of successful endeavours of this kind exist in Canada.
- Government responsibility for protecting water quality related to agriculture includes education and training, policy and programs with environmental goals that target high-risk areas (e.g., areas of intensive crop and livestock production), and regulatory controls.

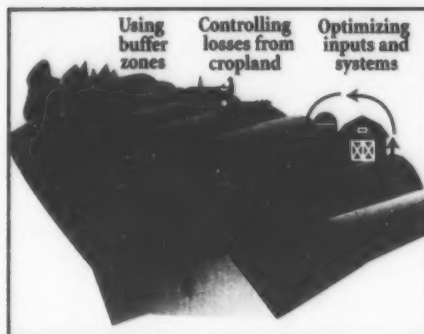
Introduction

Protecting water quality is a concern for all Canadians. Farmers are the first to be affected by pollution from farm-derived substances. It is in their best interest to take steps to protect water quality, rethinking the way resources are used and balancing production goals with the need for environmental quality. The benefits they reap by reducing the pollution resulting from agriculture may include greater efficiency and productivity, lower production costs, and improved health for

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Protecting water quality often becomes a community concern, bringing the interests of farmers together with those of many other water

Figure 8-1
On-farm approaches to
maintaining water quality

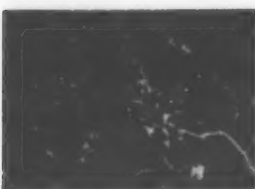


Source: A. Michaud

Erosion control practices



Strip cropping



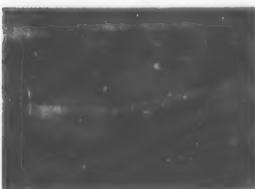
Intercropping



Winter cover cropping



*Conservation tillage and crop
residue management*



Contour cultivation

users. Community efforts to protect water quality must focus on the whole watershed and involve people with various backgrounds and interests. Governments also play a key role in protecting water quality, mainly by creating and enforcing legislation and regulations and designing policies and programs that promote agricultural sustainability and consider all outcomes—economic, environmental, and social.

This chapter examines management practices that can be used by farmers to protect water quality. It also looks at how industry, communities, and government have been effective in working with farmers to achieve this goal.

The role of farmers

The interest and participation of farmers is fundamental to the objective of protecting and maintaining water quality. Their cooperation is especially needed in three areas (Fig. 8-1):

- controlling the processes that move soil and agricultural inputs off farmland into water (e.g., by surface runoff, erosion, and drainage)
- improving the management of agricultural inputs (e.g., fertilizers, manures, and pesticides) and the efficiency with which they are used in farming systems. This strategy involves matching and timing inputs to crop needs, adding them so that nutrients and pesticides remaining in the system at the end of the growing season are not at risk of entering waterways through surface runoff or leaching.
- making use of *buffer zones* (e.g., grassed

or treed borders and artificial impoundments). These areas can trap and use pollutants that may escape from farmland before they enter streams and wetlands.

The following discussion includes research results related to these three areas. As well, we also present pertinent findings of the 1995 Farm Inputs Management Survey (nutrients and pesticides) carried out by Statistics Canada in cooperation with Agriculture and Agri-Food Canada.

Land management

Because soil and water degradation are closely linked, many practices that now show some potential to reduce agricultural contamination from nonpoint sources were first developed to conserve soil, particularly to control runoff and soil erosion. These practices also help to reduce the transport of pollutants (nutrients and pesticides) contained in the runoff, either in solution or attached to eroding soil particles. Practices that help to conserve both soil and water quality include

- crop rotations (including reduced frequency of summerfallow)
- conservation tillage systems
- the use of cover crops and *shelterbelts*.

Crop rotations

Where soil moisture is adequate, alternating annually cultivated crops with forages (e.g., grass, clover, and alfalfa) for several years and eliminating summerfallow (bare soil conditions) offers denser crop cover, which protects the soil better. Crop rotations that include forages effectively reduce runoff, erosion, and nutrient losses. For example, a New Brunswick study showed that nitrate leaching was greater under corn than under grass, and that summerfallowing after plowing under leguminous forage can lead to substantial nitrate leaching (Table 8-1).

Forages also help to improve *soil structure*. Better-structured soils are less vulnerable to runoff and erosion. The longer the time under forages, the more they improve. This effect persists for some years after annual crops are reintroduced. Figures 8-2 and 8-3 show the positive effect of rotations.

Table 8-1

Nitrate leaching under grass–summerfallow and grass–fertilized corn rotations in New Brunswick

Year	Grass–summerfallow		Grass–fertilized corn	
	Crop and nitrogen application (kg N/ha)	Nitrate–nitrogen in leachate (mg N/L)	Crop and nitrogen application (kg N/ha)	Nitrate–nitrogen in leachate (mg N/L)
1988	Grass (0)	1	Grass (20)	1
1989	Summerfallow (0)	15	Silage corn (100)	6
1990	Summerfallow (0)	14	Silage corn (100)	4

Source: Milburn and Richards, 1991

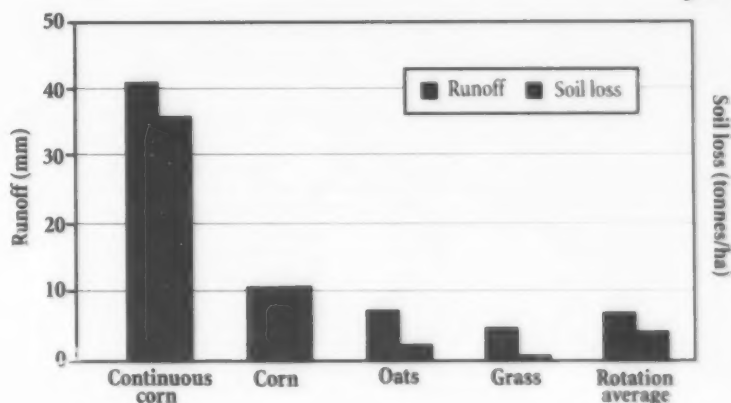
On average, the corn rotation generated less runoff and soil loss than continuous corn. As well, compared with monoculture, growing corn in rotation reduced nutrient loss.

A study in British Columbia found that including summerfallow in the rotation increased soil loss significantly and runoff to a lesser extent. Such losses arise from the soil being exposed to wind and water where plant cover is absent (if a crop is not grown and weeds are controlled to conserve soil moisture) and where the small amount of crop residues are tilled into the soil. Summerfallow may also contribute to greater risk of herbicide loss after it is applied in the following spring, if wet conditions promote runoff and leaching.

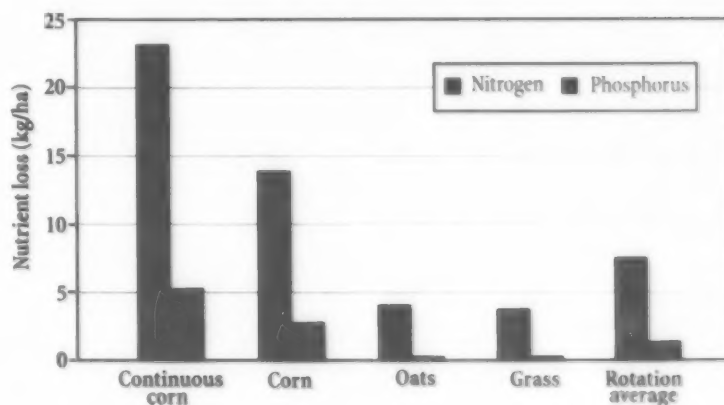
In a Saskatchewan study, nitrate concentrations in snowmelt runoff from summerfallowed fields consistently exceeded those in runoff from cropped fields. Although sediment loads were high in runoff from summerfallow, nonsediment phosphorus concentrations in runoff did not differ between cropland and summerfallow.

Crop rotations also help to control weeds, insects, and disease. Thus they not only reduce the amount of pesticides leaving farmland in runoff and leachate but also reduce the need for pesticides in the first place.

Figure 8-3
Annual nutrient losses
under continuous corn and
a rotation of corn, oats, and
grass



Source: Ripley et al., 1961



Source: Burwell et al., 1975

Table 8-2
Annual runoff, erosion, and phosphorus losses under conventional and conservation tillage practices in Quebec

Crop	Tillage practice	Runoff (cm)	Soil loss (tonnes/ha)	Total P loss (kg/ha)
Grain corn	Conventional	5.3	6.6	3.9
	Chisel	2.9	1.5	1.1
	Ridge till	3.2	1.8	1.4
Grain corn	Conventional	4.9	16.9	3.0
	No-till	1.8	1.3	0.2
Barley	Conventional	2.9	1.3	2.9
	No-till	2.6	0.9	1.1

Source: McRae et al., 2000

Conservation tillage

Tillage frequency, timing, and intensity affect the amount of runoff and losses of soil, nutrients, and pesticides. Conservation tillage is reduced tillage that leaves a 30% or greater cover of residue from the previous crop on the soil surface. It includes various systems ranging from chiseling to no-till (also called direct seeding). The main objective of these systems is to keep organic residues at or near the soil surface and to minimize the loss of organic matter from lower horizons. Residue cover protects the soil from the impact of raindrops and delays the initiation of, and slows down, surface runoff. Preventing the loss of organic matter can improve soil structure and permeability and decrease erodibility. Generally, the more residues left at the surface, the greater the protective effect.

Various studies, at spatial scales ranging from experimental plots to whole watersheds, have demonstrated these benefits:

- In a Quebec study, researchers measured less runoff and soil erosion for corn and barley under no-till compared with under conventional tillage (Table 8-2). However in another study in southwestern Ontario, runoff volumes were slightly higher for no-tilled than conventionally tilled corn over a 3-year period on a clay loam soil with a 0.5% slope.
- For cereal grains grown in the Peace River region of British Columbia, annual rates of erosion were about half with reduced tillage and only 20% with no-till compared with conventional tillage. Eliminating cultivation in the fall by leaving cereal-grain stubble and crop residues intact on the surface after harvest protects the soil from snowmelt erosion. This conservation practice can reduce winter soil loss by 80 to 95% in cereal production on sloping land in this region.
- In a watershed-scale study, researchers in Saskatchewan found that snowmelt runoff from long-term zero-tillage was less than half that from conventionally tilled fields. Improved infiltration under long-term zero-tillage also reduced the potential for runoff during summer storms.

Pesticide losses by surface runoff can also be reduced with conservation tillage. In southern Quebec, researchers recently reported that no-till reduced the surface runoff losses of a mixture of the herbicides atrazine and metolachlor by an average of about 90% compared with conventional tillage.

The practice of *cross-slope cultivation*, which creates mini-ridges in the field, helps slow down and lessen runoff on sloping land, which reduces soil loss. Research into the effectiveness of cross-slope cultivation and planting for a row crop and for cereal grain has shown that most soil loss and runoff can be controlled, provided that the slopes for row crops are very gentle (i.e., not exceeding 5%). In a comparative study of two potato fields in New Brunswick, researchers found substantial reductions in the soil lost from the field under cross-slope cultivation with *terraces* and *grassed*



Grassed waterway

Table 8-3
Seasonal runoff and soil loss from potato rotations under different management in New Brunswick

Crop and year	Accumulated rainfall ¹ (mm)	Diversions and grassed waterways		Up- and down-slope cultivation	
		Runoff (mm)	Soil loss (kg/ha)	Runoff (mm)	Soil loss (kg/ha)
Grain/ryegrass, ² 1990	707	32	106	25	285
Potatoes, 1991	582	42	1678	203	15 604
Potatoes, 1992	652	20	1156	159	21 825
Barley, 1993	687	8	63	34	489
Potatoes, 1994	583	14	200	182	24 852

¹ Between 1 May and 30 November.

² Diversions/grassed waterway site was in grain, up- and down-slope cultivation site was in ryegrass.

Source: McRae et al., 2000

Table 8-4
Average number of bare-soil days per hectare in a year

Province	Cropland area (1 000 ha)	Number of bare-soil days			
		1981	1991	1996	Reduction from 1981 to 1996 (%)
British Columbia	566	45	37	34	25
Alberta	9547	86	73	67	22
Saskatchewan	14 399	111	93	88	21
Manitoba	4699	81	65	65	20
Ontario	3545	113	110	96	16
Quebec	1739	63	61	62	2
New Brunswick	135	66	59	57	14
Nova Scotia	112	50	35	34	31
Prince Edward Island	170	103	96	94	9
Newfoundland	7	43	25	24	44
Canada	34 919	98	83	78	20

Source: McRae et al., 2000

waterways compared with the field with up- and down-slope cultivation and no erosion control (Table 8-3).

As part of the recent national agri-environmental indicator project, an indicator was developed to assess the amount of soil cover by crops and residue on Canada's cropland. This indicator was based on the number of bare-soil days, a measure of how many days a year the soil is left without

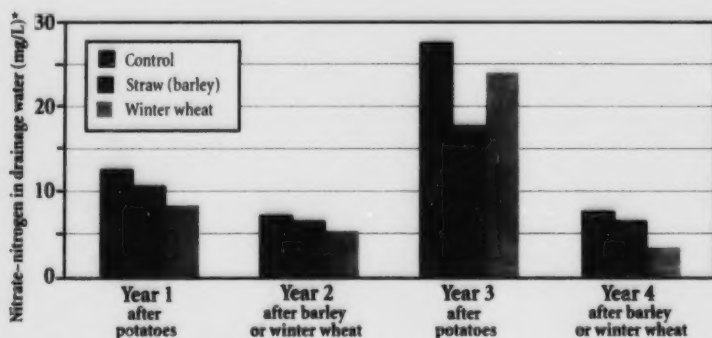
cover under various crop types, tillage practices, and shifting summerfallow ratios. Between 1981 and 1996, the average number of bare-soil days on Canadian cropland dropped by 20%, from 98 to 78 (Table 8-4). All the provinces and ecoregions, except Quebec's St. Lawrence Lowlands, also showed a drop in the number bare-soil days, indicating that soil cover improved over this time. This improvement also points to a

Table 8-5
Effect of timing and method of killing red clover forage on nitrate content of subsurface drainage water in Prince Edward Island

Treatment to kill red clover	Nitrate-nitrogen in drainage water (mg/L)		
	Same year	Next year	Next time red clover in rotation *
	Fall	Spring	Fall
Early fall tillage	13.4	8.6	19.3
Early fall herbicide	11.5	7.7	9.2
Late fall herbicide	10.5	7.4	6.2

* 3-year rotation of potato-barley-red clover.

Source: J.A. MacLeod, Agriculture and Agri-Food Canada, Charlottetown, P.E.I.



* Flow-weighted mean concentrations

Source: Milburn et al., 1997

Figure 8-4
Effect of winter cover crops on nitrate levels in tile drainage water

potential drop in the risk of soil erosion and the movement of agricultural contaminants into water.

Tillage tradeoffs

Tillage tradeoffs are one example of the choices farmers face when trying to address concerns over water quality. Although reduced tillage may take care of excessive runoff, it can also increase infiltration and aggravate the potential for leaching. Under conservation tillage, the more water infiltrates into the soil and the faster this occurs, the greater the risk of nitrate and pesticides entering tile drainage water or groundwater. The results of some studies confirm this possibility. In humid areas, techniques such as a water management system (see Box, p. 98) can help to avoid, or at least minimize, this side-effect on subsurface-drained land.

Minimum or no-till practices generally increase the amount of organic matter in the soil. As this material decays, more soluble phosphorus (the form most easily used by plants) becomes

available for runoff. As well, coarser soil fractions are less easily eroded than the finer fractions. Because carbon, nutrients, and pesticides (see Table 5-1, p. 44) readily attach to the fine soil particles, eroded sediments become enriched in these substances. As a result some studies have shown that conservation tillage practices may increase the concentrations of nutrients in surface runoff.

Under certain circumstances, this increase may even be enough to offset the benefits of the reduced volume of runoff, so that waterway loadings of contaminants may be increased. For example:

- In a Quebec study, no-till reduced the losses of phosphorus and potassium (both mainly particulate) from corn fields by 94% and 73% compared with conventionally tilled corn. However, the losses of highly soluble nitrate grew by 23%.
- An Ontario study reported greater annual losses of nitrogen in surface runoff under no-till treatments (2.9 kilograms of nitrogen per hectare per year) than under conventional tillage (1.6 kilograms nitrogen per hectare per year).

Higher levels of organic matter also result in cooler, wetter soil conditions that could delay seeding on soils with high clay content. As well, weed populations can increase under reduced tillage and no-till, especially on summerfallow in the Prairies. In this case, weed control may require the use of more herbicide or a different herbicide, and possibly different management practices. More research is needed to give a complete picture of the pros and cons of conservation tillage.

Cover crops

Cover crops are used to minimize the effects of the main crop. They provide a protective cover that reduces the risk of runoff and erosion between two growing seasons. There are two main types of cover crop. *Intercrops* are grown along with the major crop. For example, a forage crop can be seeded between corn rows or spring wheat underseeded with red clover. *Green manures* are crops that are generally sown after the main crop has been harvested. Although their use is limited following long-season crops such as corn, they are well adapted to small grain or vegetable production (e.g., ryegrass after tomatoes).

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Cover crops also act as a *sink* for nutrients remaining in soils, preventing their loss by runoff or leaching. This function is particularly important with respect to nitrogen. Plowing under these crops or spraying them with herbicide in the late fall or early spring increases the availability of the nutrients to the following crops. However, the timing of these activities affects the nitrate content in drainage water (Table 8-5).

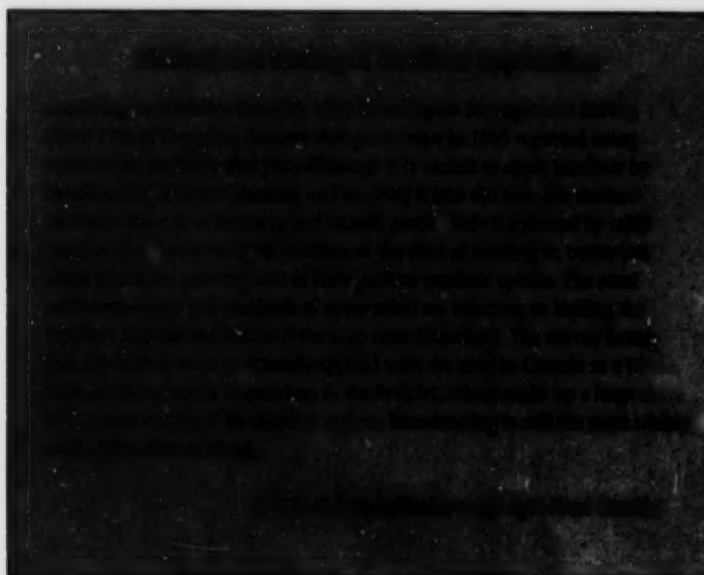
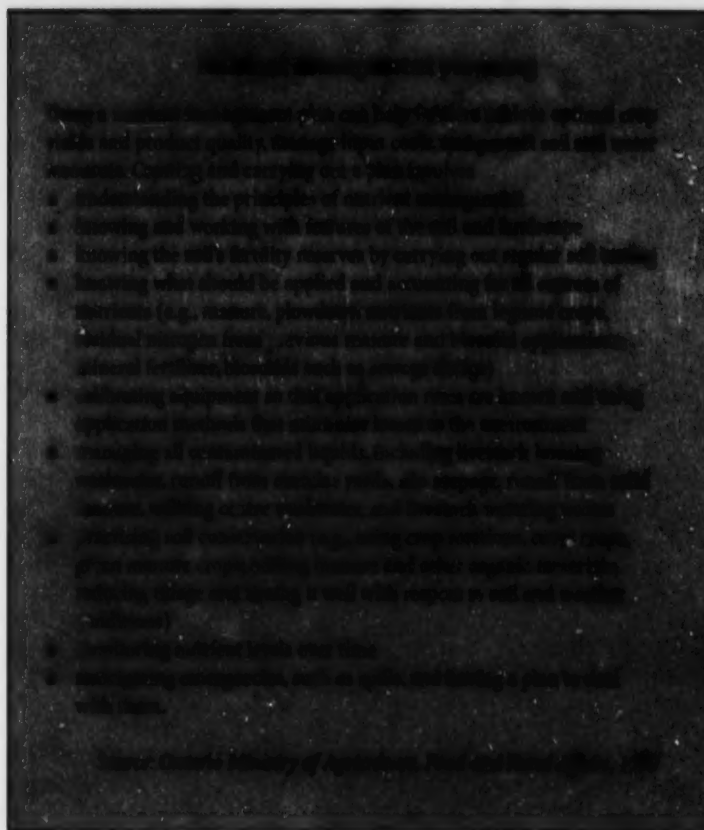
Other benefits of cover crops include

- weed control
- maintenance of organic matter
- nitrogen fixation when legumes are used
- reduced wind erosion and damage to young plants.

Among the drawbacks of cover crops are that they compete with the main crop for water and nutrients and add to production costs. The severity of these negative aspects varies with local agri-environmental conditions.

In Ontario, intercropping silage corn with red clover resulted in 40 to 87% less runoff and 46 to 78% less erosion (depending on the time of year) compared with conventionally grown corn. In Quebec, intercropping grain corn with a timothy-alfalfa mix reduced soil loss by 35% and phosphorus loss by 25% compared with corn under conventional tillage.

Winter cover cropping is a recommended practice on sloping land in the Lower Fraser Valley and east Vancouver Island regions of British Columbia, where 75% of the annual rainfall (about 1500 millimetres at Abbotsford) falls from October to April. In row crops (e.g., corn and strawberries), an estimated 20% of rainfall leaves the fields as runoff; this value may be as high as 50% for single storm events. In a British Columbia study of the benefits of winter cover cropping, soil loss was reduced by 78% for strawberries and 76% for silage corn when a winter cover crop was grown between the rows. In Prince Edward Island, winter wheat and straw mulching after potato crops reduced nitrate levels in tile drainage water (Fig. 8-4). Studies in other countries have shown that nitrogen leaching can be reduced by 31 to 77% when nonleguminous cover crops are added to different cropping systems.





Cover crops also act as a *sink* for nutrients remaining in soils, preventing their loss by runoff or leaching. This function is particularly important with respect to nitrogen. Plowing under these crops or spraying them with herbicide in the late fall or early spring increases the availability of the nutrients to the following crops. However, the timing of these activities affects the nitrate content in drainage water (Table 8-5).

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Nutrient management planning

Using a nutrient management plan can help farmers achieve optimal crop yields and product quality, manage input costs, and protect soil and water resources. Creating and carrying out a plan involves

- understanding the principles of nutrient management
- knowing and working with features of the soil and landscape
- knowing the soil's fertility reserves by carrying out regular soil testing
- knowing what should be applied and accounting for all sources of nutrients (e.g., manure, plowdown nutrients from legume crops, residual nitrogen from previous manure and biosolid applications, mineral fertilizer, biosolids such as sewage sludge)
- calibrating equipment so that application rates are known and using application methods that minimize losses to the environment
- managing all contaminated liquids, including livestock housing washwater, runoff from exercise yards, silo seepage, runoff from solid manure, milking centre washwater, and livestock watering wastes
- practising soil conservation (e.g., using crop rotations, cover crops, green manure crops; adding manure and other organic materials; reducing tillage and timing it well with respect to soil and weather conditions)
- monitoring nutrient levels over time
- anticipating emergencies, such as spills, and having a plan to deal with them.

Source: Ontario Ministry of Agriculture, Food and Rural Affairs, 1999

Method and timing of fertilizer application

According to Statistics Canada's 1995 Farm Inputs Management Survey, about 72% of Canadian farmers that grew crops in 1995 reported using commercial fertilizer that year. Although it is easiest to apply fertilizer by broadcasting it before planting and working it into the soil, this method increases the risk of leaching and runoff, particularly if followed by rainy weather. It is better to apply fertilizer at the time of seeding or, better yet, when plants are growing and at their peak of nutrient uptake. The most environmentally safe methods of application are injecting or knifing the fertilizer into the soil between the crop rows (banding). The survey found that fertilizer is most commonly applied with the seed in Canada as a whole, because this practice is common in the Prairies, which make up a large share of Canada's cropland. In all other regions broadcasting is still the most widely used application method.

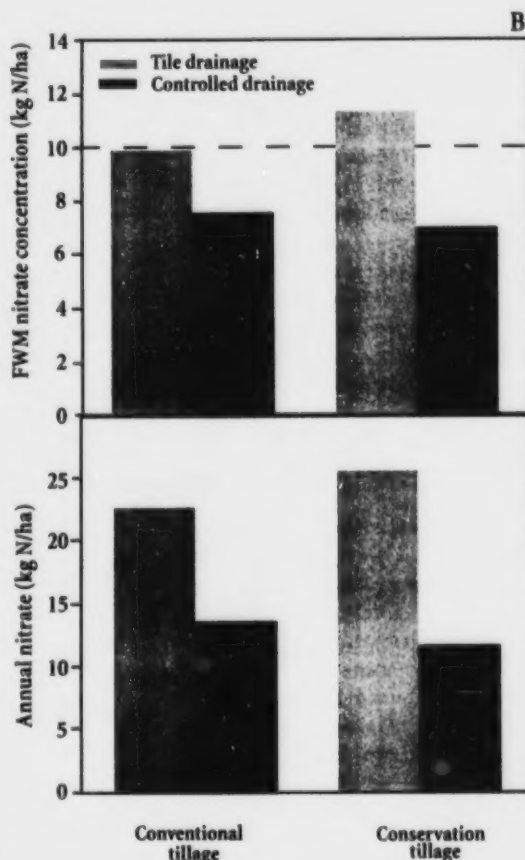
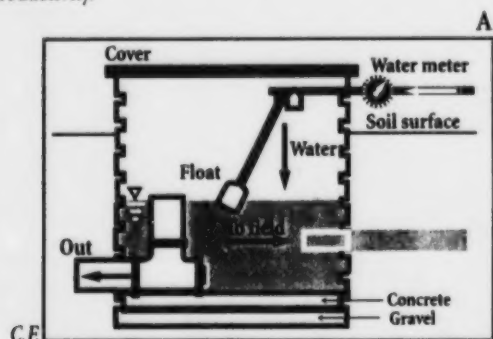
D.W.H. Culver, Agriculture and Agri-Food Canada

Water table management system in Ontario

Conservation tillage systems affect both the mechanism of water loss (surface runoff or tile drainage) and soil physical and chemical properties that affect crop growth and nutrient uptake. Conservation tillage systems retain greater amounts of crop residues on the soil surface, which slow water movement and thereby increase water infiltration. Further, in no-till systems, preferential flow through old worm channels and decayed roots and between macroaggregates also increases water movement through the soil. This additional water loss can enhance nitrate transport through the soil.

One of the technologies developed to optimize yields and reduce residual nitrate levels in humid regions with subsurface-drained land is the water table management system. This technology uses a controlled chamber with a riser attached to the tile outlet. The height of the riser is adjusted during the year for unrestricted tile drainage (during planting and harvesting periods) or controlled drainage (Fig. A). In addition, if a water source exists, the field can be subirrigated through the tile lines. This technology captures some soil water from precipitation in the early part of the growing season and enables crops to use this water in dry periods, as well as irrigation water if it is available. Alleviating crop water stress also enables the crop to take up greater amounts of nutrients, thereby increasing yields and reducing the amount of residual nitrate left at the end of the growing season that could otherwise be lost through leaching in the non-cropping period.

Over a 3-year period (1991–1994), 5800 tile water samples were collected and analyzed for nitrate content and loss. The flow weighted mean (FWM) nitrate concentrations of the tile drainage treatments were 9.9 milligrams of nitrogen per litre for the conventional tillage treatment and 11.4 mg N/L for the conservation tillage treatment (Fig. B). When controlled drainage–subirrigation systems were employed, the FWM nitrate concentrations were reduced by 23 to 39% to 7.6 mg N/L for the conventional tillage treatment and 7.0 mg N/L for the conservation tillage treatments, values within the water-quality guideline of 10 mg N/L. The annual nitrate loss for the tile-drainage treatments ranged from 23 to 26 kilograms of nitrogen per hectare, and these losses were reduced by 40 to 55% with the controlled drainage–subirrigation treatment. It was concluded that the water table management system is one new technology that reduces nitrate loss through tile drainage and increases water and nitrogen uptake, thereby improving crop productivity.



Drury and C.S. Tan, Agriculture and Agri-Food Canada

Input and waste management

Curbing the movement of agricultural inputs (e.g., nutrients and pesticides) into water is one way of reducing water pollution. Another way is to reduce the amount of these inputs that is available to be moved off farmland into water, by increasing the efficiency of input use. Greater efficiency can be achieved by

- matching the amount of input applied to the amount needed for production
- managing inputs to maximize their use by crops or animals and reduce the residual amounts left at the end of the production cycle.

Proper waste management is another component of protecting water quality. Such management involves both reducing the amount and hazardous composition of waste, and undertaking its safe handling, storage, and disposal.

Nutrients

All locations and soils have potential yields limited by environmental factors such as climate, slope, soil texture, natural fertility, and drainage. Acknowledging these constraints and setting realistic yield objectives will help in matching nutrient inputs to the actual needs of crops. A close match greatly reduces the potential for nutrient leaching and runoff.

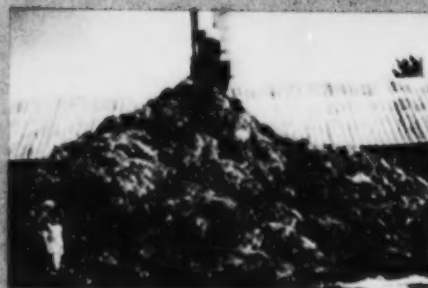
Good nutrient management begins with knowing how much nitrogen, phosphorus, and potassium is already in the soil. Regular soil testing provides this information and helps to prevent applying mineral fertilizers when high levels of nutrients are already present in the soil. The 1995 Farm Inputs Management Survey indicated that 60% of Canadian farms use soil testing, with about 75% of them testing every 1 to 3 years. Work is still needed to improve the quality of soil testing and to encourage the whole farming community to adopt this practice. Some farmers do not believe there is an economic return to soil testing. At one time provincial governments provided soil testing services to farmers free of charge, but today farmers must pay for each soil sample (e.g., Ontario laboratories charge about \$12 for a basic soil analysis for pH, phosphorus, potassium, and magnesium).

Once nutrient levels in soil are known, effective management involves

Manure storage on Canadian farms

Manure was stored on 60% of Canadian farms in 1995. Of these, 11% stored manure in liquid form (91% of hog farms, 30% of chicken farms, and 9% of cattle operations) and 89% stored it in solid form. Open storage systems (e.g., lined and unlined lagoons and open tanks) may be the least environmentally safe methods, because the manure is exposed to precipitation and is in direct contact with the ground, increasing the risk of runoff and leaching. However, in regions with low precipitation, where soil conditions are suitable and storage volumes are adequate, there may be little risk posed by open storages that are lined. Open storages were the most widely used methods in 1995. For example, 91% of Canada's cattle producers store manure in solid form, mainly in an open pile with no roof (accounting for 54% of cattle) or as a manure pack (42%). The safest method, covered storage, was seldom used, except on chicken farms, 43% of which used sealed covered tanks.

D.W.H. Galver, Agriculture and Agri-Food Canada



Plowing under liquid manure



Application of solid manure



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D.W.H. Culver, Agriculture and Agri-Food Canada



Plowing under liquid manure



Application of solid manure



Table 8-6

Nitrogen loading in surface runoff, under two manure treatments on cornland in south coastal British Columbia

	Control (no manure applied)		Fall-applied manure left on exposed soil surface		Manure applied in fall to winter cover crop	
	1996	1997	1996	1997	1996	1997
Runoff (mm)	277	536	283	531	247	127
Sediment (kg/ha)	12 692	7679	7740	7717	1767	1923
Nitrate-nitrogen (kg N/ha)	0.2	1.5	0.3	2.0	0.2	0.7
Ammonium-nitrogen (kg N/ha)	0.7	4.2	2.0	8.5	1.9	6.0
Organic nitrogen (kg N/ha)	29.1	36.9	26.4	72.5	12.7	35.5

Source: van Vliet et al., 1999

- accounting for all nutrient sources, including fertilizers, manures, residues from the previous crop, biological fixation of nitrogen, and mineralization of soil organic matter
- fertilizing according to a *nutrient management plan* that matches nutrient inputs to crop needs; this plan considers factors such as the previous crop, tillage practices, sources of nutrients (chemical or organic) and their availability (see Box, p. 97 top)
- using nutrients in a way that optimizes uptake (see Box, p. 97 bottom); for example, for crops with a high demand for nitrogen such as corn and potatoes, the nutrient can be split into smaller quantities and applied several times over the growing season, or, for high-value crops such as processing tomatoes, the nutrient can be added continuously through liquid fertilization systems using irrigation lines
- preventing the buildup of nutrients, especially phosphorus, in upper horizons of the soil.

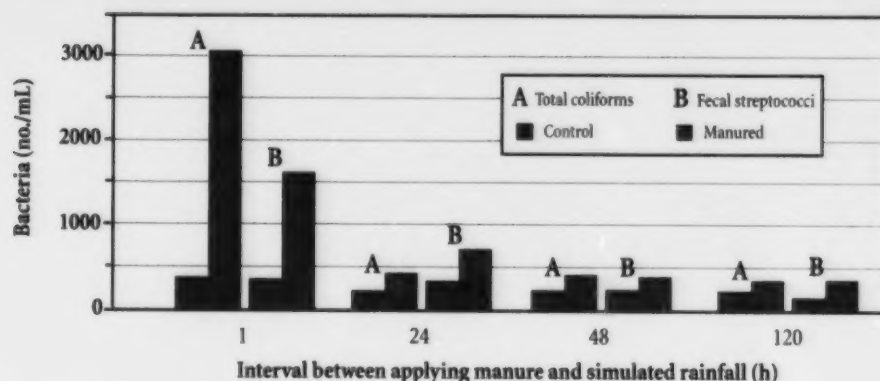
Manure is a natural by-product of livestock operations that can be either an asset or liability.

On the one hand, manure contains organic material and crop nutrients that, added to soil, help to build *soil tilth* and *fertility*. On the other hand, nitrate, phosphorus, bacteria, and salts from manure can contaminate groundwater and surface water. This risk can be greatly reduced with proper handling, storage, and timing of land application of manure.

Safe storage allows the producer to store manure until conditions are suitable for land application. For example, applying manure in the fall and winter, when no plants are present to take up the nutrients, can lead to nutrient leaching and runoff. Winter applications should be especially avoided; in Quebec they are prohibited. Having the capacity to store manure during these periods (ideally for more than 250 days) allows for the manure to be applied under more suitable field and weather conditions. Proper storage also reduces or eliminates the risk of contaminated runoff from the storage site (see Box, p. 99).

Environmentally sound practices for applying manure include

- knowing the nutrient content of the manure. Nutrient content varies considerably between manure types, management practices (storage time and



Source: Grando, 1996

Figure 8-5
Bacteria counts in runoff from plots that received surface application of liquid manure and simulated rainfall in Quebec

facilities), and animal management practices (type of feed, food retention efficiency of animals). Relying on average numbers when planning the use of manures can result in under- or over-fertilizing soils.

- calculating the amount of manure to be applied based on the most-limiting nutrient and not on the one required by crops in the greatest quantities. Most of the time, producers should estimate the application rate from the phosphorus content, since the nitrogen-to-phosphorus (N:P) ratio of manure is generally lower than the N:P ratio in crop nutrient requirements. Basing manure applications on nitrogen often results in adding phosphorus in excess of crop needs, leading to phosphorus buildup in soils.
- incorporating manure into the soil and avoiding applications to frozen ground. These practices reduce the risk of surface runoff of phosphorus and ammonium. Ammonium may become toxic to fish at high concentrations.

In a 2-year comparison of two manure management systems in south coastal British Columbia, manure was applied in the fall. It was found that there was less potential for nitrogen loading of surface water when the manure was applied to a winter cover crop than when it was left on the exposed soil surface (Table 8-6).

Research is under way to reduce the environmental effects of manure application to soil by

- modifying feeds and feeding systems to

Integrated pest management

Integrated pest management involves various combinations of practices that include:

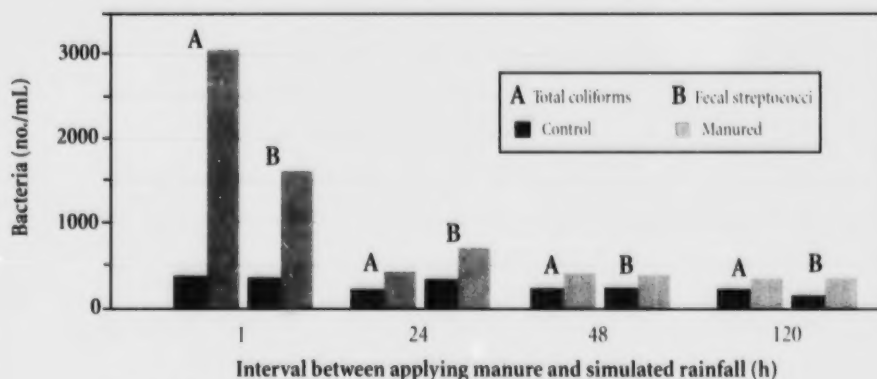
- site selection: choosing sites that are best suited to growing healthy crops
- cultivar selection: choosing crop varieties that are resistant to key pests
- nutrient and water management: providing the materials needed to grow a crop that is capable of resisting or tolerating pest and disease damage
- crop rotations: alternating crops to break up the habitat conditions that encourage pest development
- planting and harvesting strategies: timing planting and harvesting to avoid pest peaks
- physical control: removing weeds by cultivation, hoeing, or hand weeding; controlling weed growth with mulches and mowing
- sanitation: eliminating places or materials where pests live and reproduce, using clean seed, removing pest-ridden plant debris, and cleaning storage and handling equipment
- trap crops: planting crops to lure pests away from the main crop
- biological controls: encouraging pest enemies that occur naturally in the agroecosystem or releasing new control species
- pesticide: using chemical controls

The net result is that the amount of pesticides used is reduced.

Source: Ontario Ministry of Agriculture, Food and Rural Affairs, 1996

reduce nitrogen and phosphorus levels in manure

- developing new handling and application technologies
- examining new crops and cropping strategies to better use manure nutrients



Source: Grando, 1996

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Pesticide application in Canada

Herbicides can be applied at various stages of crop development. When they are applied before planting or before the crop emerges, the farmer does not yet know the actual weed conditions. In this case, the herbicide is used as an insurance against weeds. It is better to deal with weeds only when they reach a level that threatens the farmer's economic returns. Statistics Canada's 1995 survey of farm inputs management showed that the stage of crop growth was the most commonly used indicator of when to apply herbicides on Canadian farms. Economic injury, the most environmentally safe method of determining if and when to apply herbicides, was used for 20% of Canada's cropland.

Precise application of pesticides is one way to reduce their movement into groundwater and surface water. Pesticide label directions specify the rate at which the product should be applied. Most modern spraying equipment can deliver pesticides at the correct rates if the equipment is properly maintained and calibrated. Ideally, sprayers should be calibrated between applications of different pesticides. According to the survey, about 76% of Canadian producers who applied pesticides in 1995 operated their own sprayers. Of these, about 68% (representing about 54% of the cropland area receiving pesticides) calibrated their sprayers only at the beginning of the season; only 16% re-calibrated them between applications of different pesticides.

D.W.H. Culver, Agriculture and Agri-Food Canada

- developing new techniques of manure composting
- using *biotechnology* to develop livestock that make better use of phosphorus in feed, leaving less in manure.

Livestock manure is the main source of agriculturally derived bacteria in water. A Quebec study showed that loss of bacteria from manure is greatest when the manure is left unburied on the soil surface and exposed to rain shortly after application (Fig. 8-5).

Pesticides

Pesticides are most effectively used along with a variety of other pest control methods (*see* Box, p. 101). Monitoring pests is an important component of pest control. Monitoring may involve examining the crop visually, trapping and sweep-netting of insect pests, and watching for weather conditions that may signal changes in pest populations. One option is to join a pest detection network that monitors the development of pest populations and advises farmers when pesticides should be applied. Participation in

these groups generally results in fewer applications and use of less pesticide, which in turn reduce costs and environmental risks. If pesticides become a necessary option, it is best to

- select products that are target specific; least persistent; and of low toxicity, low vapour pressure, and low susceptibility to leaching
- follow the guidelines for application rate and conditions (applying too much pesticide is environmentally hazardous and expensive, but applying too little may cause pests to become resistant to the effects of the pesticide)
- choose application methods that direct the pesticide at the appropriate target rather than generally applying it to a whole field
- calibrate application equipment regularly (*see* Box).

Industry and monitoring agencies are working together to identify undesirable environmental outcomes and react to correct them. For example, to respond to concerns for environmental quality, permitted use patterns for atrazine have been changed, the original form of metalochlor removed from the market voluntarily by the manufacturers, and aldicarb removed from registration in Canada.

Waste

Farm operations, like all human activities, produce waste. Many provincial agencies have guidelines or manuals on best management practices to deal with these wastes. Sources of waste that must be handled carefully to prevent effects on water quality are

- milkhouse washwater
- livestock housing washwater
- silo seepage
- exercise yard and feedlot runoff
- dead stock
- used oil
- pesticide containers.

Dairy operations, in which there is widespread use of pipeline milking systems, often have problems with waste waters. Water used to clean these systems becomes contaminated with phosphates from detergents and the 5 to 10 litres of milk left in the system each day. To prevent the entry of phosphorus and milk solids into surface water, milkhouse washwater must be managed

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properly. This management may include

- pre-rinsing the pipelines and feeding the rinsewater to older calves
- storing the washwater in the manure storage system or in a separate tank and applying it to soil when conditions are appropriate
- using a treatment trench system, which operates like a septic system, settling out the solids in the milk washwater and allowing the liquid to seep into soil through trenches of crushed stone.

Buffer zones and shelterbelts

Despite the careful use of inputs and soil conservation practices, some potential contaminants may still leave agricultural fields. To prevent them from entering waterways, they can be trapped in buffer zones at the edge of the fields or in locations in the landscape where runoff occurs.

Buffer zones are areas or bands of natural or planted vegetation located between agricultural land and water bodies. These zones of permanent vegetation are generally covered with grasses (e.g., filter strips or grassed waterways) or with natural vegetation of grasses, shrubs, and trees (*riparian zone*). Impoundments receiving drainage waters from agricultural land can also function as buffer zones.

Along with other ecological benefits (see Chapter 7), buffer zones improve water quality by filtering incoming runoff and seepage waters and reducing their content of sediments and dissolved and particulate pollutants. A recent review of many studies on the filtering capacity of buffer zones reported sediment-trapping efficiencies ranging from 50% to nearly 90% for grass buffer strips 1 to 9 metres wide. The efficiency generally increases with strip width. Similar results were reported for forested buffers 10 to 60 metres wide. Buffer zones are effective in filtering out sediments when the water flow is shallow and uniform, but concentrated flow tends to reduce this effectiveness. Riparian trees and shrubs have also been shown to anchor stream bank soils and help stabilize eroding gullies. This stability reduces the amount of sediment entering water from stream bank erosion.

The amount of phosphorus retained by buffer strips varies with the form of phosphorus. Total phosphorus is trapped in proportions ranging from 20 to 90%, mainly because of the settling of particulate forms. Dissolved phosphorus is less efficiently retained by buffer zones. Some studies have shown that over time buffer zones can accumulate materials rich in phosphorus and eventually become sources of soluble phosphorus. Ponds and wetlands can also trap phosphorus, particularly during the low-flow conditions of summer. However, some of this phosphorus is likely to be released during high-flow conditions of fall or spring.

Nitrogen leaving cultivated areas can also be trapped by buffer strips. Like phosphorus, particulate forms are retained more efficiently than dissolved forms. In one study, buffer strips reduced total nitrogen by 63 to 76% and nitrates by 27 to 57%, with 9-metre bands being more efficient than 4.6-metre bands. In another study, grassed buffers were more efficient at removing sediment-bound and organic nitrogen from runoff waters than forested buffers of the same width.



Shelterbelt

Nitrates in subsurface flow are a major form of environmental losses of nitrogen. Some researchers have concluded that riparian buffers play an important role in controlling these losses through uptake of nitrogen by the riparian vegetation and by encouraging denitrification of nitrate to the gases nitric oxide, nitrous oxide, and nitrogen gas, although these may contribute to atmospheric levels of greenhouse gases. The relative importance of these two processes under different agri-environmental conditions is not clear.

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Peer activities in British Columbia

Peer activities in British Columbia involve peer advisory services to help reduce pesticide and herbicide use and runoff from the province. These groups are supported by B.C. Environment and the B.C. Ministry of Agriculture and Food.

When a consultant is needed, a peer adviser is selected from a community group.

- Investigate the situation
- Select a representative committee from the community to work with the consultant
- Develop a strategy with the consultant to reduce pesticide and herbicide use
- Select the action to be implemented and assign responsibility

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Pesticides leaving cultivated fields by surface runoff can also be retained to some extent by filter strips. In a U.S. study, losses of the herbicide atrazine were reduced by 32% and 55% by 4.6- and 9.1-metre buffer strips, respectively. In France, 57% of the herbicides isoproturon and diflufenican was trapped by a 5.7-metre buffer strip and 68% by an 11.1-metre buffer.

Shelterbelts are trees and shrubs that are planted to reduce wind erosion. They also curb the pollution of water systems by fine, wind-blown soil particles that are generally high in organic matter, nutrients, and often contain pesticides. In winter, shelterbelts help to reduce the movement of snow and can help to reduce peak runoff flows in springtime. Studies in some countries have shown that tree buffers can also filter some of the spray aerosols drifting in the air from cultivated areas, reducing atmospheric deposition of these pesticides on surface waters.

The role of the agricultural industry

The agricultural industry has become increasingly aware of its environmental responsibilities in recent years. Three important ways that the industry is supporting the move toward greater environmental sustainability are creating and promoting *codes of practice* and *peer advisory programs* and encouraging farmers to develop *environmental farm plans*.

Codes of practice

Codes of practice are an effective tool to introduce the concepts of conservation and agricultural sustainability to members of the agricultural sector. They are most effective when initiated by members of the industry itself with the assistance of scientists and other professionals. They comprise guidelines that producers can follow to ensure that their management practices are environmentally sustainable. Their intention is to encourage producers to use those practices that work best for the environment.

In adhering to a code of practice, producers benefit by

- protecting the water they use
- establishing a reputation as an environmentally conscious member of the industry
- improving their ability to get bank financing and insurance
- protecting themselves against environmental liability, because they are less likely to damage the environment and more likely to have a record of thoughtful management
- protecting themselves against nuisance complaints (in many provinces, right-to-farm legislation is in place to protect producers from such complaints as long as they are complying with regulations, guidelines, and codes of practice)
- qualifying for government incentive programs, in some jurisdictions.

Codes of practice help the agriculture industry as a whole because they provide farmers with a means of exerting peer pressure on fellow farmers who do not comply with the environmental objectives of the code. They also provide

government personnel who are reviewing a nuisance complaint with a tool to assess whether a producer is conforming to acceptable practice.

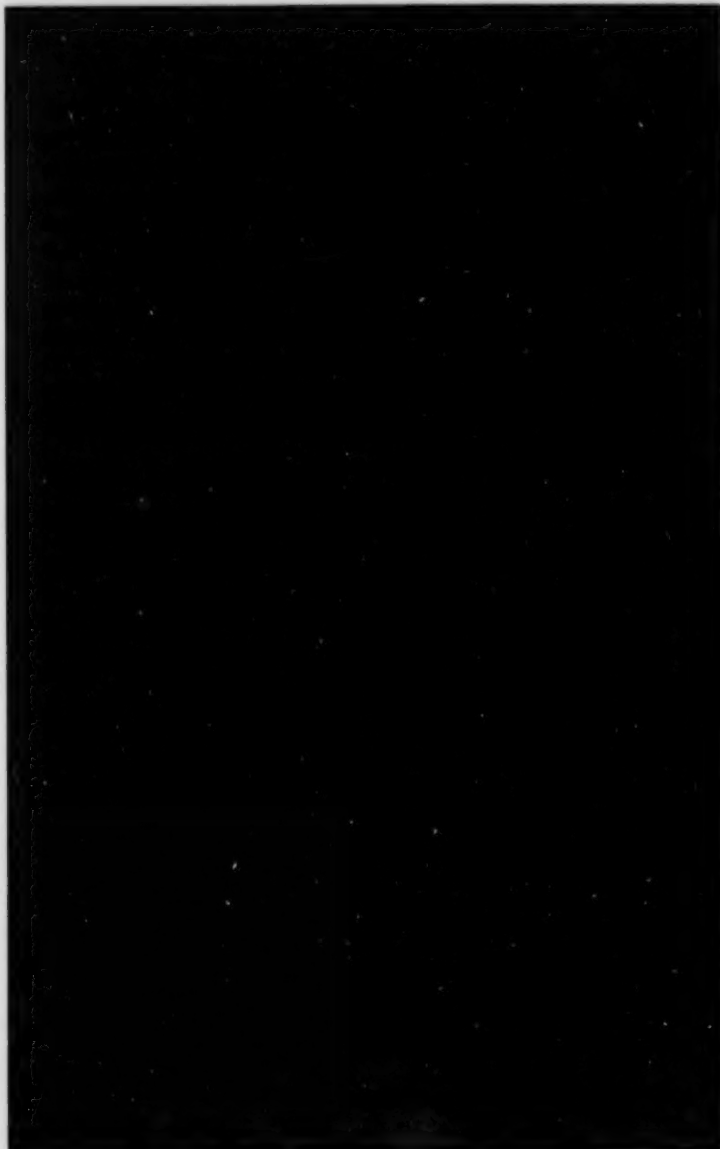
In some provinces, codes of practice are embedded in legislation. For example, British Columbia's *Waste Management Act* empowers the provincial environment ministry to control pollution resulting from various forms of waste. Under this Act, the Agricultural Waste Control Regulation makes specific provisions to control waste arising from the production of crops and livestock, the operation of equipment for agricultural waste management, and the application of fertilizers and soil conditioners. The Code of Agricultural Practice for Waste Management is embedded in this regulation and describes practices for using, storing, and managing agricultural waste in an environmentally sound manner. Producers operating in compliance with the code are exempt from the act's requirement for a waste management permit.

Peer advisory programs

In some provinces, peer advisory programs have been started to help farmers understand the concept of environmental sustainability and to avoid penalties under environmental laws. If a nuisance or pollution complaint is directed against a farmer, a peer advisor (fellow farmer) visits the farm and suggests steps that the farmer can take to comply with pertinent guidelines, codes, or legislation. In this way, education is offered and the farmer is given the chance to comply voluntarily before regulatory agencies step in and order corrective measures (see Box opposite).

Environmental farm planning

Making changes in agricultural practice for the benefit of the environment, including improving water quality, depends on the interest and cooperation of farmers. Environmental farm plans are a practical way to involve farmers and help them make their operations more environmentally sustainable. Such plans are voluntarily prepared by a farm family to identify their operation's environmental strengths and weaknesses and to set realistic goals to improve environmental conditions within the limits of



time, equipment, and finances. They help to balance the economic and environmental goals of farming and encourage farmers to adopt the best management practices that support these goals (see Box).

Although environmental farm plans are designed and carried out by farmers, training, advice, and practical assistance are offered through various government programs and by industry agencies. For example, environmental farm planning programs are administered in Ontario by the

Peer advisors in British Columbia

Producer organizations in British Columbia operate peer advisory services to help resolve nuisance and pollution complaints against farms in the province. These groups are supported by B.C. Environment and the B.C. Ministry of Agriculture and Food.

When a complaint is received, a peer advisor (a volunteer from a commodity group)

- investigates the complaint
- writes a report, including corrective measures that must be taken and the time within which this must happen, and sends it to the farmer
- conducts a follow-up visit to see that the farmer has complied with the instructions
- refers the case to the appropriate government agency if the problem persists.

Trained advisors are located throughout the province. Training covers environmental standards, reporting methods, ways to get technical assistance to the farmer, and guidelines for involving a regulatory agency. Although most complaints are dealt with first through this program, farmers are at all times subject to the provisions of the law and can be held responsible for causing pollution.

Source: B.C. Ministry of Agriculture and Food, 1995

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Environmental farm planning in Ontario

Ontario's Environmental Farm Plan (EFP) Program began in 1993 as a pilot program in seven counties. By voluntarily completing an environmental farm plan, farm families can identify the environmental strengths and weaknesses of their operations and create an action plan that can help them farm more sustainably. Under the program, farmers attend a workshop where they receive an EFP workbook that outlines farm features that can be addressed, from water wells to wildlife. After completing a self assessment of their farms and developing an action plan for those components that apply to their farms, participants submit the plan for confidential peer review. By June 1999, about 16 000 individual farm families had participated in at least one component of the program. To assist farmers in carrying out their action plans, an incentive of up to \$1500 per farm business is available.

The Coulter family of Grey County qualified for a grant and also won an EFP award for their innovative solution to the need for better quality water on their farm. A spring had provided a dependable supply of good drinking water for five generations on their farm. But when the water was tested in 1996 to secure financing, high levels of coliform and *E. coli* were found. To remedy this problem, the old well house was removed, and the soil around it was excavated to a depth of about 2 metres. A 0.6-metre layer of crushed stone was added, and a new concrete tank was positioned over the spring source. A hole punched in the bottom of the tank allows the spring to bubble through the gravel and collect in the tank, which acts as underground storage. An overflow pipe takes excess water safely to a nearby stream. The area around the tank was backfilled with clay soil, sloped, and seeded to direct water flow away from the top of the tank. Heavy concrete lids provide access for routine inspection and maintenance. Bacterial testing is now done twice a year.

As a result of this innovation, the Coulters once again enjoy a steady supply of clean water and are enthusiastic about the Environmental Farm Plan program. The work on the well complements another project on the farm to fence cattle out of the stream. The creek now runs narrower and cleaner, and brown trout have been recently sighted downstream.

H.B. Rudy and A. Graham, Ontario Soil and Crop Improvement Association

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Ontario Soil and Crop Improvement Association and the Ontario Ministry of Agriculture, Food and Rural Affairs. In the Atlantic provinces, the program was initially coordinated by the Atlantic Farmers Council, with technical assistance from the Eastern Canada Soil and Water Conservation Centre. It is now administered by provincial farming groups.

The role of the community

After a decade of effort, North American programs such as Canada's Green Plan and the Rural Clean Water Program in the United States have shown that tangible improvements in the quality of surface water in agricultural watersheds can be achieved only through the active participation of the rural community. The most sophisticated contamination prediction models, competent extension staff, and generous financial assistance programs cannot improve water quality without the commitment of farmers and other community residents.

Before they can deal with the issue, the concerned community must agree on the need for intervention. The form this intervention takes depends on the value the local community places on the environment and the protection of various water uses. Building awareness of the issues among the potential partners is an essential first step in establishing a watershed management group (see case study on the Boyer River, p. 107 and Box, p. 109). The effectiveness of this first action is enhanced if leadership is taken by farmers and other land users.

The diversity of interests, responsibilities, and expertise needed for this type of project requires

a coalition to be created at the scale of the target area, including municipalities, private and public agricultural and environmental consulting services, local representatives of governmental organizations, interest groups and private organizations, community groups, and farmers who cultivate lands within the watershed (see case study on Waterloo region, p. 108). Such a coalition may seem difficult to create and operate but will produce considerable dividends in terms of coherence and ownership of the project by all participants.

The role of government

Policy and programs

Legislation and regulation tend to deal with pollution after it has occurred (see Chapter 11). In principle, the federal government favours preventing pollution over treating it. In *Pollution Prevention—A Federal Strategy for Action*, released in June 1995, prevention was ranked at the top of a hierarchy of activities to deal with pollution, followed by recovery, control, disposal, and remediation.

To encourage pollution prevention and resource conservation, policies and programs have been developed in all parts of the country. Under these initiatives, information, technical assistance, and sometimes financial incentives are made available to farmers to encourage them to adopt conservation practices that protect soil, water, and air. For example, in 1998 the British Columbia government launched its action plan "Tackling Nonpoint Source Water Pollution in British Columbia," which combines education, planning, incentives, and regulations to improve rural water quality.

Conservation practices that prevent, or at least reduce, the movement of agricultural substances into water are needed, especially in the areas at greatest risk. Most pollution occurs in localized areas of watersheds. In fact, many studies have shown that a small portion of a watershed may be responsible for most of the pollutant loadings of a watercourse. Targeting efforts to prevent pollution in these areas makes the best use of today's limited resources and encourages a streamlining of government policies and programs. It is a priority to identify these areas, a task that may be

Case study

Bringing back to health the Boyer River, Quebec

Thirty years ago the Boyer River was a prolific spawning ground for smelt and a popular spot for swimming. After years of industrial, municipal, and agricultural pollution, the river is so full of nutrients and suspended sediment that the smelt fishery has collapsed and swimmers go elsewhere.

Located near Quebec City, on the south shore of the St. Lawrence River, the Boyer River drains a watershed of 21 700 hectares. About 60% of this area is farmland, much in high-density livestock production. More than half the area's 275 farms produce hogs. Nutrient-laden runoff from these farms has contributed to pollution of the river—excess nutrients in this watershed (the amount left in the system after crops are harvested) are estimated at 317 tonnes of phosphorus and 630 tonnes of nitrogen annually.

To restore the water quality of a river successfully, the entire watershed population needs to be involved. So, in making a plan to rehabilitate the river, organizers realized the importance of getting people to understand

- the nature and extent of the water-quality problem
- the importance of environmental quality to the economic development of the region
- ways they could participate in renewing the river.

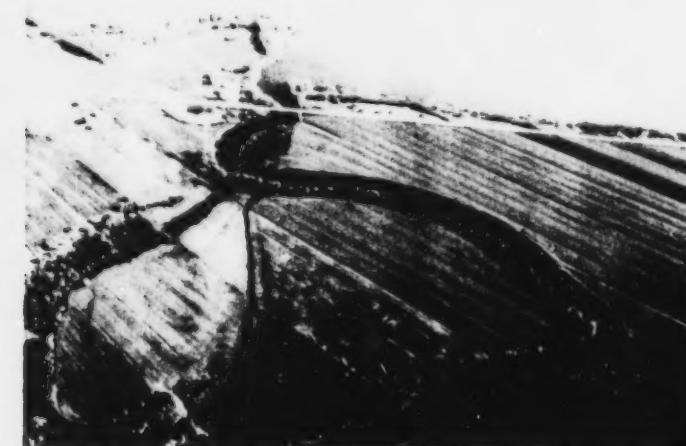
To get the work started, a committee was formed (the GIRB, groupe d'intervention pour la restauration de la Boyer), with representatives from farmer groups, municipalities, and the provincial ministries of agriculture and environment. A logo was designed and the newsletter "Au courant" was created. The

committee organized many public information meetings and training sessions on subjects such as integrated fertilization, waste recycling, and composting.

The committee also obtained assistance from provincial and federal governments, as well as the private sector, to get access to specific programs for water clean-up and to introduce resource-conservation practices. For example, these programs allowed some farmers to build appropriate manure storage structures and to complete engineering works for stabilizing river banks, managing animal watering places, and restricting animal access to the river. Farmers also worked with an expert in agriculture and environment ("éco-conseiller") to develop best management practices.

This project has created a feeling of identity, membership, and cooperation among people within the watershed, which will be invaluable in future endeavours.

C. Bernard, Institut de recherche et de développement en agroenvironnement
M.R. Laverdière, Université Laval
M.C. Nolin, Agriculture and Agri-Food Canada



Case study

Developing partnerships between government and farmers in the Regional Municipality of Waterloo, Ontario

The Regional Municipality of Waterloo (the Region) is located in the Grand River watershed in south-central Ontario. The Region is responsible for water supply and wastewater treatment for about 400 000 people in seven area municipalities. It accounts for more than 50% of the population in the Grand River watershed, which covers an area of about 7000 square kilometres. About 93% of the watershed area is rural and 7% is urban.

Recent work in the Region indicates that 70% of the total phosphorus load to the river is from rural nonpoint sources (i.e., mainly runoff from agricultural land). About 17% is from municipal wastewater treatment plants. More detailed work on a major tributary to the Grand (the Nith River) indicates that 40 to 99% of the total phosphorus load is from rural nonpoint sources, depending on flow conditions and time of year. Based on these and similar studies, the Region has concluded that water quality in the Grand River and its tributaries is not likely to improve significantly until the rural nonpoint sources of contamination are addressed. Controlling or reducing such sources will benefit the Region by

- improving the security and reliability of drinking water supplies
- deferring or reducing the cost of wastewater treatment plant upgrades
- avoiding or deferring absolute constraints on expansions of these treatment plants.

In recognition of the benefits of reducing rural impacts on water quality, the Rural Water Quality Program was approved in principle in April 1997. The program provides financial incentives to rural landowners to implement measures to improve surface and groundwater quality.

The Region has provided \$1.5 million in funding over 5 years for the program. Other agencies (including the National Soil and Water Conservation Program and the Grand River Conservation Authority) are also contributing cash or in-kind support to the program.

Development of the program has been guided by a steering committee of interested local and provincial groups. Members include local commodity groups, the Ontario Federation of Agriculture, the Ontario Soil and Crop Improvement Association, the Ontario Farm Environment Coalition, and various provincial government ministries. The steering committee developed eligibility criteria, measures to be funded, funding levels, and application and approval procedures. This cooperative approach resulted in a program that meets the needs and interests of all the stakeholders.

By the end of 1998, more than 90 proposals had been received from interested farmers. Fifty-two projects were approved, with total program funding of \$260 000. Participating farmers will contribute significant resources (cash and in-kind) to these projects, so the total value of the projects implemented will be considerably greater. Among the projects approved are manure storage facilities and associated nutrient management plans, milkhouse washwater treatment systems, clean water diversions from manure storages, and restricted livestock access to waterways.

The program provides significant benefits to all the partners. The region benefits from the improved reliability of drinking water supply and wastewater treatment. Participating farmers receive technical and financial assistance to implement measures that, in many cases, provide economic and environmental benefits to them. Such measures improve farm sustainability, long-term productivity, and profitability. The entire Grand River watershed community will benefit from the resulting improvement in water quality. A final, intangible benefit is that the urban and rural communities are developing a better understanding of each others' needs and interests.

M.L. Murray, Regional Municipality of Waterloo

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more complicated than first appears. Some agricultural situations that appear to pose a risk to water quality may, in fact, have little or no effect, while apparently nonproblematic situations may present serious risks of pollution and require corrective actions. Mathematical models that reproduce the physical and chemical behaviour of watersheds may be useful in identifying high risk areas and developing corrective plans.

Incentive mechanisms

Regulatory control of environmental degradation has tended to focus on environmental damage after it occurs. In contrast, incentive mechanisms encourage industry to reduce or prevent pollution. Incentive-based approaches have been promoted to deal with point-source pollution because of their effectiveness in meeting a given environmental objective at least cost.

Examples of incentives to control water quality include

- fees levied on actual or estimated discharge of pollutants into the water to force the polluter to pay for at least some of the damage caused. However, such charges are hard to apply to most agricultural residues that travel by diffuse and indirect pathways over a potentially long period to receiving water bodies.
- taxes or subsidies on the quality of a receiving water body, or on farm inputs and management practices. These would be forfeited if pollution control was inadequate.
- liability, which makes polluters responsible for the damage to water quality they cause.

Because it is often difficult to get the information needed to use incentives based on water quality, environmental policies in agriculture have tended to use taxes and subsidies to influence production decisions. For example, a number of European countries and the United States have levied taxes on farm inputs, particularly fertilizer and pesticides. Such taxes can be administered readily, and the revenues can be used to support environmental programs that educate farmers and promote the adoption of good management practices. Alternatively, financial incentives can be offered in the form of a grant for adopting an environmentally sound practice or a payment for producing an environmentally benign product,

such as in the rural water quality program, described in the Waterloo region case study, p. 108.

Performance bonds work well for problems involving well-understood costs of damages resulting from the observable actions of a few farmers, but such conditions are rare (an example is waste transport by custom operators). Liability rules are only suited to certain situations in which polluting events are infrequent, there are few parties involved, and the cause and effect linkages are well understood (e.g., accidental spills of manure or pesticides).





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Oldman River Basin Water Quality Group

The Oldman River basin is the most intensive agricultural area in Alberta, featuring irrigated agriculture and intensive livestock operations. Lethbridge, Alberta's third largest city, and numerous towns and villages are located within the basin. Water quality in the basin is of growing concern, as agriculture and food-processing industries continue to expand to serve growing international markets.

The Oldman River Basin Water Quality Group is the initiative of a large group of individuals and agencies interested in maintaining the health of the Oldman River basin, its tributaries, and the surrounding lands. Members represent a wide range of groups, including agricultural producers, environmental groups, government agencies, municipal agencies, cities and towns, academic institutions, and Aboriginal groups, and also include interested citizens.

In December 1997, a water-quality workshop was held in Lethbridge to assess the current state of water quality in the Oldman River system and its irrigation return-flow channels. Participants recommended that a comprehensive plan for the basin be developed to integrate

- educating and making people aware
- assessing current land use in the basin
- implementing management practices that do not negatively affect water quality
- monitoring water quality in the basin to identify and assess the impact of various activities and to determine the effectiveness of management practices in improving water quality.

The group drafted the Oldman River Basin Water Quality Initiative Action Plan in March 1998. This 5-year plan is an action-based response that will allow all stakeholders to participate in developing policies to protect the quality of surface-water resources.

J.J. Miller, Agriculture and Agri-Food Canada

The costs incurred by farmers to reduce pollution, and by regulators to monitor and enforce compliance, must be compared with the benefits generated by any incentive in terms of improved water quality. Because of the regional diversity of farming in Canada, controls and incentives must be chosen and applied to suit local conditions.

Also, because of the difficulty of tracing nonpoint source pollution, the best answer may lie in technological developments to reduce farm inputs, such as nutrient management, including precision farming and variable-rate application of inputs. Business-led initiatives, such as the registration process for the International Standards Organization environmental quality for agriculture (ISO 14000), also have a role.

Financial incentives could be used to encourage the adoption of environmentally sound practices. Canadian examples of such assistance have generally focused on reducing soil erosion and have been universally available rather than targeted at producers causing the problem.

Given the difference in farms and their environmental impact, the efficient policy choice will be a system of management incentives tailored to local conditions. Incentives for relatively low-cost nutrient management plans may be sufficient in some locations to improve water quality. In other areas, such as those with heavy concentrations of livestock, a combination of policy and regulatory tools may be required. In any case, farmers can anticipate that environmental controls on their way of farming will become more stringent over time, requiring them to invest thought, time, money, and other resources to ensure compliance.

Conclusion

Many avenues exist to reduce agricultural contributions to declining water quality. In the past decade, many Canadian farmers have adopted farming practices aimed at soil and water conservation, but much remains to be done. Nutrient management, particularly as it relates to manure storage, handling, and application, integrated pest management, and control of soil degradation—the processes that contribute directly or indirectly to water pollution—all need wider commitment by farmers. At the same time,

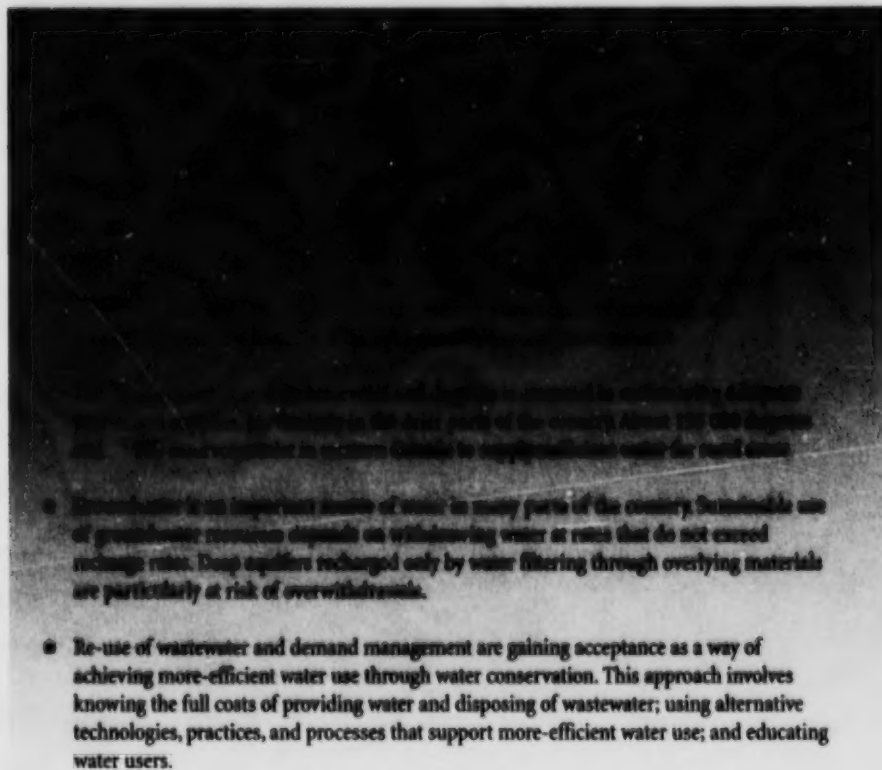
continued research is essential, and governments need to give more attention to policies and programs that support environmental sustainability. They should also undertake economic assessments to better establish the benefits to farmers and to society of improving water quality.

Regional research and Agriculture and Agri-Food Canada's national agri-environmental indicator project both point to areas of intensive cropping and livestock production as the source of most water quality problems caused by agriculture. These areas are expected to expand as pressures mount to meet growing world demands for agricultural products. More intensified farming leads to greater use of energy and resource inputs and greater potential for environmental degradation unless there is a strong incentive to value environmental health as much as production goals and profit.

Public opinion on water quality and market pressures fueled by consumers' choice of products produced in an environmentally sustainable way may eventually dictate how agricultural production is carried out. But both these forces are reactive. Agriculture must continue to take steps to address its contribution to environmental degradation and seek ways to restore and protect water quality before public opinion against farming practices escalates to the point at which strict regulatory controls are applied. The real challenge is to achieve environmental goals within the economic reality facing farmers.

9. Maintaining Reliable Water Supplies

J. Sketchell, A. Banga, P.Y.T. Louie, N.J. Shaheen, T.W. Van der Gulik, and R.J. Woodvine



- Groundwater is an important source of water in many parts of the country. Sustainable use of groundwater resources depends on withdrawing water at rates that do not exceed recharge rates. Deep aquifers recharged only by water filtering through overlying materials are particularly at risk of overwithdrawals.
- Re-use of wastewater and demand management are gaining acceptance as a way of achieving more-efficient water use through water conservation. This approach involves knowing the full costs of providing water and disposing of wastewater; using alternative technologies, practices, and processes that support more-efficient water use; and educating water users.

Introduction

An adequate supply of good-quality water that is available year round is essential for all human activities. Concerns continue to mount regarding the availability of water as demands and competition for water grow in all sectors of society. Management of water supplies must consider all competing uses of water, including those associated with agriculture, industry, municipalities, recreation, and aquatic ecosystems.

This chapter looks at the effects of drought on water supplies, the management of surface water, and the replenishment of groundwater. It also examines strains on the water supply, and how to balance demand with supply and share water among its many users. Because water is in

shortest supply in the semi-arid interior of British Columbia and on the Prairies, examples are most frequently taken from these regions.

Drought

Drought is a prolonged period of abnormally dry weather that depletes water resources. Because most human activities and ecosystems are dependent on reliable adequate water resources, the impacts of drought are far reaching. Drought affects our lives by

- putting stress on water and food supplies
- degrading the environment through poorer water quality and more forest fires,



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Highlights

- A sufficient supply of good quality water is needed for agricultural activities such as irrigation and livestock watering, as well as for domestic, municipal, industrial, recreational, and instream uses.
- Droughts are sure to occur but difficult to predict. They occur most often in dry regions, such as the Prairies, although other parts of Canada may have shorter, less serious periods of drought. Drought threatens both crop and livestock production. With the potential threat of global warming and increasing trends in population, urbanization, and consumptive use, the impacts of drought can only become more serious.
- The development of storage reservoirs and dugouts is essential to maintaining adequate year-round supplies, particularly in the drier parts of the country. About 155 000 dugouts and 21 500 reservoirs exist in western Canada to supply sufficient water for rural areas.
- Groundwater is an important source of water in many parts of the country. Sustainable use of groundwater resources depends on withdrawing water at rates that do not exceed recharge rates. Deep aquifers recharged only by water filtering through overlying materials are particularly at risk of overwithdrawals.
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- soil erosion, and insect infestations
- affecting the economy by reducing the capacity for agricultural production, power generation, transportation, and manufacturing.

In agricultural terms, the moisture deficit caused by drought places farmland soils at risk and poses a threat to both crop and livestock production. Severe droughts can cause millions of dollars in losses to farmers.

Although drought can occur in every type of climate, semi-arid regions, such as the interior of British Columbia and the southern part of the Prairies, are most vulnerable, because they are usually moisture deficient already and have highly variable precipitation. Drought can affect areas from the size of a city to an entire continent. Of all meteorological hazards, drought is probably the slowest to develop, lasts the longest, and is the least predictable.

Three basic types of drought may occur separately or simultaneously:

- *Meteorological drought* occurs when precipitation is significantly below normal over a long period.
- *Agricultural drought* occurs when low soil moisture and scarce water supplies stunt crop growth, reduce crop yields, and endanger livestock.
- *Hydrological drought* occurs when a lengthy meteorological drought causes a sharp drop in the levels of groundwater, rivers, and lakes.

The timing of a drought may determine its type. For example, summer drought usually causes more problems because it coincides with the time of highest water demand.

Western Canada has experienced at least 40 severe droughts in the past 200 years. The most severe was the prolonged drought of the 1930s, when the Prairies received about 40% less precipitation than normal. Saskatchewan's worst drought was in 1961, when precipitation was 45% of normal and losses in wheat production alone were \$668 million. Droughts were also frequent during the 1980s. The summer of 1988 was the hottest on record for many regions in Canada; rainfall during the growing season across the southern Prairies averaged 50 to 80% of normal. This drought affected all economic sectors. In

agriculture, grain production was down 31% from 1987, and export losses were estimated at \$4 billion. Droughts also occur in eastern Canada, but they are usually shorter, smaller in area, less frequent, and less severe.

Although droughts occurred widely and frequently in the 1980s in Canada, evidence is insufficient to suggest a trend. Droughts also occurred frequently in the 1890s and 1930s and are considered to be part of natural climate variability. Global warming scenarios show that drought frequency and severity are expected to increase where precipitation does not make up for the increased water losses from evaporation. However, the uncertainty in climate models, particularly related to precipitation, makes it difficult to predict confidently where, when, and to what degree droughts will take place in the future.

Drought is the result of many factors combined, such as

- below-normal precipitation
- extended hot dry air
- already-low soil moisture.

Because of this complexity, a large range of climatic and hydrological variables are needed to monitor for and detect drought, including temperature, precipitation, soil moisture, streamflows, and water supply conditions.

Numerous drought indices have been developed in an attempt to combine the various parameters affecting drought into a single number. Examples include the Cumulative Precipitation Index, based on the single parameter of precipitation, and the more complex Palmer Drought Severity Index, based on a thorough analysis of the surface water balance and a comparison of actual values to climatically attainable values.

Drought is still a poorly understood phenomenon, and continuing research is needed to improve our capability to detect, analyze (particularly with regard to probability and extreme statistics), and predict it. The multidisciplinary nature of this research and the multisectoral impacts of drought call for an integrated effort from the physical, biological, and social sciences to develop effective responses (see Box on El Niño, opposite).

Efforts to alleviate the impact of drought range from mass migrations in the past to the



Effect of drought

development of drought-proofing technologies, crop insurance, and large-scale assistance programs. Most measures dealing with water resources have been mainly concerned with supply. Although this approach has been successful in the past, the increased storage capacity for water intended for drought protection may be used indiscriminately during years without drought, creating new water demands. The creators of these new demands then become reliant on new reservoirs as a permanent source of supply, and the ability of new reservoirs to act as a back-up source for the original users is impaired. When drought recurs, the impacts would likely be even greater than if new reservoirs had never been built. The demand side of the water supply-demand equation should be carefully examined when developing plans for drought protection.

Surface water management

Water managers in the Prairie region are faced with managing the extremes of floods and droughts, while maintaining a reliable water supply to meet the basic needs of human life and the demands of economic development. Because of the nature of prairie hydrology, the high degree of variability of precipitation, and the short period of spring runoff, storage works must be constructed and managed to provide a year-round supply of water. These storage works take the form of reservoirs, dams, dugouts, and natural lakes (see Box, p. 114).

A significant challenge to water managers is locating surface water supplies relative to that of water users. Water users (domestic, municipal, agricultural, and industrial) usually require a number of resources and services and thus are not always located near their water source. Providing a reliable supply of water to users often requires distribution networks consisting of

- conveyance works (canals and natural channels)
- pipelines and pump plants
- diversion works, including inter-basin transfers.

About 150 000 dugouts have been excavated in the Prairies and another 5000 in British Columbia, mainly to supply rural domestic and

livestock water needs. Dugouts are typically artificial ponds that are 4 to 6 metres deep and 2000 to 6000 cubic metres in capacity, designed to provide a 2-year water supply with allowance for evaporation losses and ice formation. Excavation of larger dugouts is normally not practical, even though some regions frequently experience two or more consecutive years of low-runoff conditions. Annual net evaporation losses average about 700 millimetres and are often the largest single demand on dugouts. The formation of about 1 metre of ice over the winter months can result in poor water quality and water shortages before the ice melts in spring and storage is replenished by snowmelt runoff.

More than 21 500 reservoirs have been constructed in the Prairies and British Columbia.

1992

Over the last 30 years, strong El Niños have occurred in 1972, 1982, 1987, and 1997, when sea temperatures were warmer than normal in the eastern equatorial Pacific Ocean. The occurrence of the El Niño phenomenon and other drought events may be related, especially in the tropical regions. El Niño events affect global circulation patterns globally by altering the temperature distribution of the atmosphere around the world, which in turn causes drought conditions, sometimes to shift back. Droughts can bring drought to the world, and El Niño can bring drought to the world.

The very drier conditions of 1940, then followed the 1930s of the century, brought another devastating drought around the globe and worsened the already conditions in Canada. The winter of 1939-1940 was again another very warm, including 1930s ones. However, resulted in warmer than normal, and a better Christmas was experienced across the Prairie. Another major consequence of 1939, particularly was 20 to 40% below normal rainfall in Ontario, through the Prairie, into southern Ontario. The very conditions, the grain-growing areas of the Prairie and the southern extension in Ontario and Quebec were hit by dry conditions during a period of about 20% to the amount of precipitation. Only a small amount of the 1939-40, longer escaped the dry conditions, with the 1939-40, however, had the amount of Manitoba's precipitation for the year.

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Abstract

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Effects of El Niño

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The very strong El Niño of 1982, then dubbed the El Niño of the century, brought several devastating droughts around the globe and worsened the already-dry conditions in Canada. The winter of 1997–1998 was again affected by a record-breaking El Niño event. Edmonton recorded its warmest December ever, and a brown Christmas was experienced across the Prairies. During the spring and summer of 1998, precipitation was 20 to 40% below normal from British Columbia, through the Prairies, into southern Ontario. For the year as a whole, the grain-growing areas of the Prairies and the farming communities in Ontario and Quebec were hit by dry conditions caused by a shortfall of about 20% in the amount of precipitation. Only a narrow band along the Canada–U.S. border escaped the dry conditions, with parts of southern British Columbia and the extreme south of Manitoba actually receiving above-average precipitation for the year.

El Niño occurs periodically, suggesting some potential for drought prediction. However, until more research is completed, it remains an unreliable tool to predict the precise locations and intensities of drought conditions in Canada.

A. Shabbar, Environment Canada

Water supplies in water-poor Saskatchewan

Construction of the Gardiner Dam in 1959 to 1963 created Lake Diefenbaker on the South Saskatchewan River, about 120 kilometres upstream of Saskatoon, Sask. The Qu'Appelle Dam, needed to keep the reservoir from overflowing into the Qu'Appelle River Valley, has control works that are operated to deliver water into the Qu'Appelle River basin.

The St. Mary, Oldman, Bow, and Red Deer rivers form the headwaters of the South Saskatchewan River along the eastern slopes of the Rocky Mountains in Alberta. Although the mountain and foothills areas occupy only 15% of the area that drains to Lake Diefenbaker, they contribute 85% of the annual inflow. About 80% of this volume originates as meltwater from the snowpack at higher elevations, mainly during May and June. Major flood events can occur when heavy storms coincide with the melting of the mountain snowpack.

Managing the reservoir is the single most important component in maintaining a reliable supply of water to much of the province of Saskatchewan. Lake Diefenbaker provides water for municipal and industrial needs, wildlife, irrigation, recreation, hydroelectric generation, and flood control, and for managing downstream flows.

Through the control and regulation of flows at Lake Diefenbaker, the South Saskatchewan River supplies about 45% of the province's population with water for drinking and other municipal needs, including the residents of three major urban centres. By way of a diversion from Lake Diefenbaker down the Qu'Appelle River to Buffalo Pound Lake, water is transferred by pipeline to the cities of Regina and Moose Jaw. The city of Saskatoon and surrounding communities obtain their municipal water supplies directly from the South Saskatchewan River.

Several potash mines, located as far away as Lanigan, about 150 kilometres from Lake Diefenbaker, obtain their water supply via a network of canals and diversion works from the reservoir. Many irrigators grow mainly specialty crops on 40 000 hectares around Lake Diefenbaker and along the South Saskatchewan and Qu'Appelle rivers. Wildlife, recreation, flood control, downstream flow regulation, and hydroelectric generation interests are served mainly through regulating water level and flow.

A particular challenge of water management is to accurately forecast inflows to Lake Diefenbaker—hourly, daily, weekly, monthly, and seasonally. These forecasts are the foundation for planning the operation of the reservoir to meet the needs of each user without jeopardizing or negatively affecting other interests and the dam structures themselves.

A. Banga, Sask Water

These reservoirs are formed by dams placed across streams or rivers, or are constructed as offstream storage facilities with diversions from adjacent streams or rivers. Manitoba, for example, has a Surplus Water Initiative, whereby farmers on fully allocated streams are encouraged to build off-channel impoundments and divert surplus water during the spring runoff period. Construction of dams and reservoirs always involves at least some land and environmental losses.

The required storage capacity of a reservoir is normally determined by a water balance analysis based on a representative sequence of historic inflows and all anticipated water demands, including evaporation losses and ice formation. Some water uses (e.g., domestic) are expected to be met on a firm or guaranteed basis, whereas shortages in supply may be tolerated for others (e.g., irrigation). These demands can be reliably met unless a more severe sequence of low streamflow occurs than was considered in sizing the project (see Willow Creek Basin case study).

Widespread prairie droughts in the 1980s revealed that many individual and community supplies were not able to meet the demands placed on them during extended dry periods. In many areas the drought resulted in water rationing, pumping to fill dugouts, and emergency drilling of deep wells. More recently, rural water pipelines sourced from reliable water supplies have been used to provide secure supplies to individuals and rural communities (see Chapter 3).

Water must be reliably available not only in sufficient quantities, but also desired quality. Water for domestic uses and human consumption must generally be of the highest quality. Water for agricultural and industrial processes must have a certain chemistry. Providing water supplies of desired quality often involves treatment. In some instances it may be advantageous to use groundwater sources as an alternative to surface water supplies (see Box, p. 116).

Groundwater recharge

Groundwater recharge is water that infiltrates into the zone of saturation, also called the water table. The sustainable yield of an aquifer is mainly

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Case study

Irrigation in Willow Creek Basin, Alberta

Willow Creek is a tributary of the Oldman River in Alberta, originating in the Livingstone Mountain Range and draining an area of about 2500 square kilometres. The creek is supplied by snowmelt, and the annual water flow, though extremely variable, averaged 128 000 cubic decametres between 1916 and 1993. About 75% of the yearly flow takes place from April to June, and about 60% is too early to meet irrigation needs.

Land use in the upper basin is primarily extensive livestock grazing, with timber harvesting at higher elevations. Further south the basin is divided between ranching west of the creek and intensive dryland farming east of the creek. In a year of adequate precipitation, the agricultural zone is one of the most productive in the province. Irrigation projects are located mainly in the lower part of the basin and derive their water directly from the creek. An estimated 25 000 hectares of land could be irrigated from Willow Creek, of which 10 500 hectares could be developed by direct pumping from the creek if adequate storage was provided.

Planning studies conducted in 1976 for the Oldman River Basin predicted difficulties in meeting agricultural demands for water from Willow Creek in the mid-1980s. During a public meeting in 1979, numerous concerns were raised with regard to licensing, instream and onstream uses, flow regulation, enforcement, flow allocation, and minimum flows. By 1983, 39 irrigators were licensed to use 9000 cubic decametres of water, and in most cases these water needs were met. With many new applications for irrigation coming in the mid-1980s, it became clear that better information was needed on the actual water use and variability of demands in the basin, and in 1986 a moratorium was placed on further expansion of irrigation.

The first recorded irrigation supply shortage occurred in 1977, followed by eight consecutive years of forced irrigation shutdowns, from 1984 to 1992. Since 1992 precipitation has been high in the basin, and *watermastering* (the allocation of water, usually according to the priority of each user) was needed for only a short time in 1998. The moratorium afforded some protection of the already-dwindling water supply for existing users. However, with low precipitation during the mid-to late-1980s, existing licensees were forced to shut down their projects or share the water supply. With the forced shutdowns, licensees with newer priority numbers were unable to receive their full allocation of water. Even after the moratorium was implemented, water supply still depended on adequate precipitation. To create a fairly reliable water supply for the irrigators, it is necessary to collect spring runoff water and store it for the irrigation season.

A new storage facility with a capacity of 50 500 cubic decametres is currently under construction in the northeast of the basin. This facility will

- increase the security of the water supply for existing municipal and domestic users
- provide a secure water supply for livestock and irrigation water users
- allow for the expansion of irrigated acreage to 8500 hectares
- provide additional water-based recreational opportunities
- improve the potential for meeting instream flow needs downstream of the reservoir, with respect to both water quality and quantity.

Watermastering is currently the only effective tool to share out the limited water supply. When the new storage facility is operational, watermastering is expected to occur less often.

E. Hui, Alberta Environment



Water supplies in water-rich Prince Edward Island

Prince Edward Island is blessed with an abundant supply of water, receiving about 1100 millimetres of precipitation fairly evenly throughout the year. About 40% of this water returns to the atmosphere through evapotranspiration; 25% runs off to streams and ponds; and 35% recharges groundwater, eventually being discharged to surface water as baseflow.

The province depends nearly completely on groundwater supplies for domestic and industrial use. Groundwater is of excellent quality and can be used for drinking without being treated. An estimated 2% of the average annual recharge is used by homes, industry, and agriculture. However, in some areas with heavy industrial or municipal water demands, withdrawals may be as high as 50% of recharge, and further removal of groundwater in these areas is discouraged.

Prince Edward Island has more than 4000 kilometres of streams, which become mixed with salt water in estuaries for a good part of their length. These streams are typically short, narrow, and shallow, and about 60 to 70% of their water comes from groundwater. There are few natural freshwater lakes or ponds, but hundreds of artificial ponds. Flooding is rare, because the streams are short and the soils and bedrock are permeable.

Precipitation during the growing season is usually adequate, but supplemental irrigation is sometimes needed to obtain optimal yields. Surface water is usually preferred for irrigation because of the lower cost compared with that for groundwater. However, surface waters are often overtaxed because they are limited, and fish habitat must be protected by maintaining a minimum amount of water flow in the stream at all times.

The province has developed irrigation policy defining how to allocate available water resources among various users. It encourages extracting groundwater for irrigation, especially where surface water resources are limited or heavily used. Irrigation wells must be assessed in a manner similar to that for other high-capacity wells. Pump tests must be conducted, and the possible impacts on other groundwater users in the area and on the environment must be evaluated. If the proposed pumping conditions are sustainable, a groundwater allocation is issued.

After several dry years in the early to mid-1990s, the demand for irrigation wells increased. However, because of the costs, generally only the larger corporate farms have pursued the groundwater option. About 30 high-capacity irrigation wells now operate in the province. Wells typically extract 10 to 20 litres per second. In recent years, only three or four requests for additional irrigation wells have been received each year.

Only a limited number of permits are granted each year for surface water extractions for irrigation, and streams are monitored to ensure that the flow does not drop below the levels required to sustain the aquatic habitat. The available water (water in excess of the maintenance flow) is divided into 30 litre-per-second allotments and distributed according to a watershed priority list that considers many factors, including the historical use of the resource and date of the application. In 1998, there were 31 applications for surface water allocations, but only 24 were approved, based on the availability of water.

J.P. Mutch, Prince Edward Island Department of Technology and Environment

controlled by the amount of recharge it receives. If total discharges (natural discharge plus water use from human activities) exceed recharge, water levels in an aquifer will decline. This decline will continue until a new balance is reached between total discharge and recharge, or the aquifer becomes depleted to the point where further withdrawals are no longer feasible.

Quantifying recharge is not easy, because it depends on a number of variables including

- soil type
- geology and hydrogeology
- precipitation (including amount, type, and melt rate for snow)
- prior soil moisture conditions
- runoff
- topography
- evapotranspiration.

Quantifying the Natural Discharge of Water from Groundwater

Groundwater discharge is a natural and continuous supply of water resulting from 1000 millimeters of precipitation per year. This water is distributed throughout the aquifer, and the amount of water that is discharged to the surface is determined by the amount of water that is available in the aquifer. The amount of water that is available in the aquifer is determined by the amount of water that is recharged to the aquifer.

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- runoff
- topography
- evapotranspiration.

For a given climatic condition, recharge is much higher in areas of coarse sands and gravels than in areas of low-permeability clays (Fig. 9-1). Less than 3 millimetres of water may reach aquifers through clay soils each year, regardless of the amount of precipitation. In contrast, the annual recharge may be as high as several centimetres for gravel outcrop areas.

Groundwater levels in shallow aquifers overlain by permeable materials fluctuate according to how much recharge is received seasonally and annually. As a result, these aquifers may be sensitive to drought and in some cases may not be reliable during drought periods, particularly during longer-term droughts such as occurred in the late 1980s. They are also more vulnerable to contamination than deeper aquifers overlain by low-permeability deposits.

In semi-arid climates, a soil moisture deficit often eliminates infiltration of water into the soil. In this case, shallow depressions, or sloughs, are an important source of recharge water. Other surface water bodies, particularly wetlands, rivers, and streams, may also provide significant groundwater recharge (where the water table is below stream level, the stream will provide recharge). The relationship between surface water and groundwater is dynamic—a lake or river may recharge groundwater during periods of high surface water levels, but during drier periods the gradients may reverse and groundwater may discharge into the surface water body. High stream flows result from rainfall events or snowmelt, but the base flow in the stream during drier parts of the year frequently comes from groundwater discharge. The interaction between groundwater and lakes is less than that with rivers or streams because of the finer-grained, less-permeable materials found at the bottom of most lakes.

Many deep aquifers are recharged only by water filtering down through the overlying materials. Although recharge may be slow, it is relatively consistent, resulting in fairly stable water levels. For example, an observation well in Saskatchewan's Estevan Valley showed a maximum water level fluctuation of less than 15 centimetres from 1965 until a major groundwater production project led to a decline in water levels in 1988. Thus, these aquifers form dependable water supplies that are relatively protected from

drought conditions. However, because recharge rates may be very low, the danger is that these aquifers may be pumped well beyond sustainable yields (see Box, p. 119).

Some jurisdictions are augmenting groundwater recharge artificially by pumping water into an aquifer. Although this initiative is considered as viable storage, it can have environmental consequences that remain to be resolved. A general need exists throughout Canada for more information on groundwater resources, flow patterns, and usage.

Reclaimed water

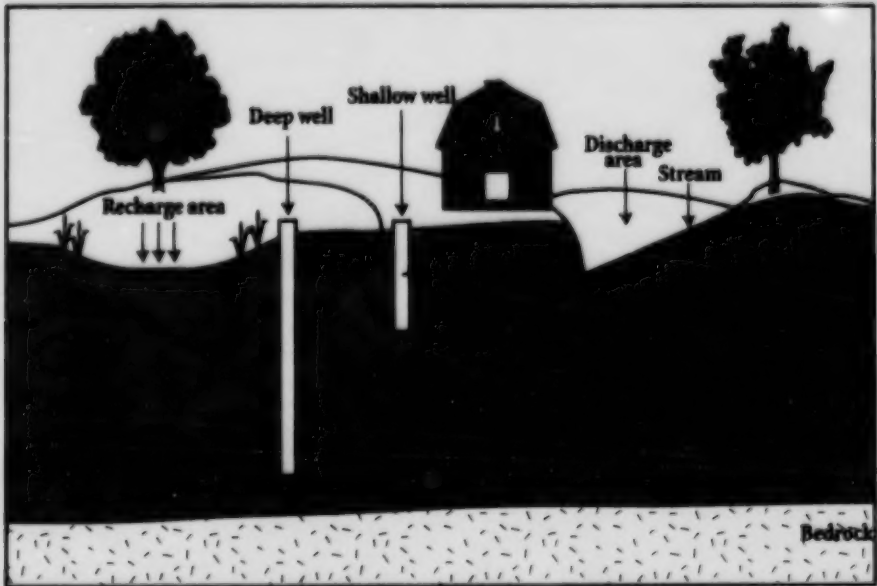
Programs for the use of reclaimed water (treated wastewater) can be an integral part of a region's liquid waste management plan, as well as a strategy for water conservation. Reducing the release of wastewater into the environment by treating the effluent and making it a reusable resource can help solve the problems of wastewater discharge and provide water for the irrigation of crops and landscapes in water-short areas (see Box, p. 118).

Balancing demand with supply

Canadians have traditionally considered water as a natural resource to be managed and controlled for human use. In meeting continually growing demands for water, we have excelled in developing and manipulating our water supply. However, the general acceptance of a supply management philosophy has contributed to high rates of water use, degradation of the water resource, and a disregard for the vital role of water in the ecosystem.

Recently, in the face of shortages of supply, concerns over water quality, and rising costs, water managers and the Canadian public have begun to recognize that demands can be altered by policy and behavioural changes. It is not always necessary to develop costly new supplies. This approach, known as demand management, is key to achieving more-efficient use of water through water conservation (Fig. 9-2).

Figure 9-1
Recharge of aquifers



The efficient use of water implies doing more with less. Efficiencies can be gained in all sectors, including agriculture, municipal, domestic, and industry. Chapter 3 includes several examples of ways to improve water use efficiency in agriculture, as well as the benefits of doing so, such as reductions in wastewater produced and energy consumed.

- Central to a successful water conservation program are an understanding of
- the water resource itself (baseline data and monitoring)
 - how, when, and why water is used (water audits and metering)
 - the full cost of providing water of suitable quality and disposing of wastewater
 - alternative water-efficient technologies, processes, and practices
 - attitudes and values related to water and the environment.

Public education and awareness are necessary tools in implementing water conservation. However, they may need to be supplemented by provincial and federal legislation and regulations and economic incentives and disincentives, including consumption-based pricing. The Okanagan case study (p. 120) illustrates how demand management principles and water conservation are being applied to a region that

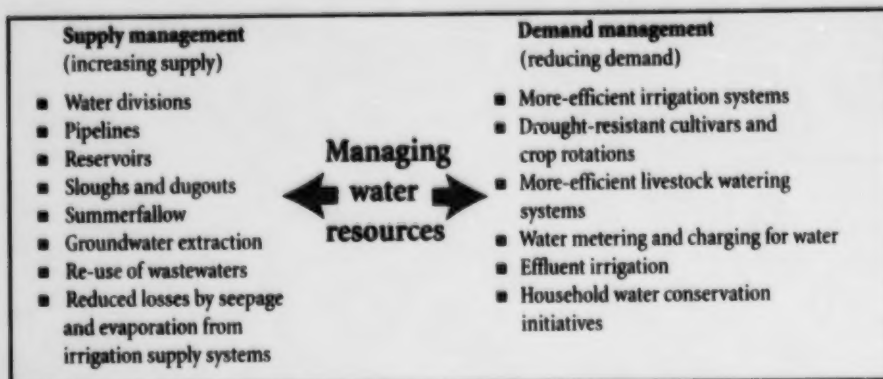


Figure 9-2
Ways to manage water resources for agriculture

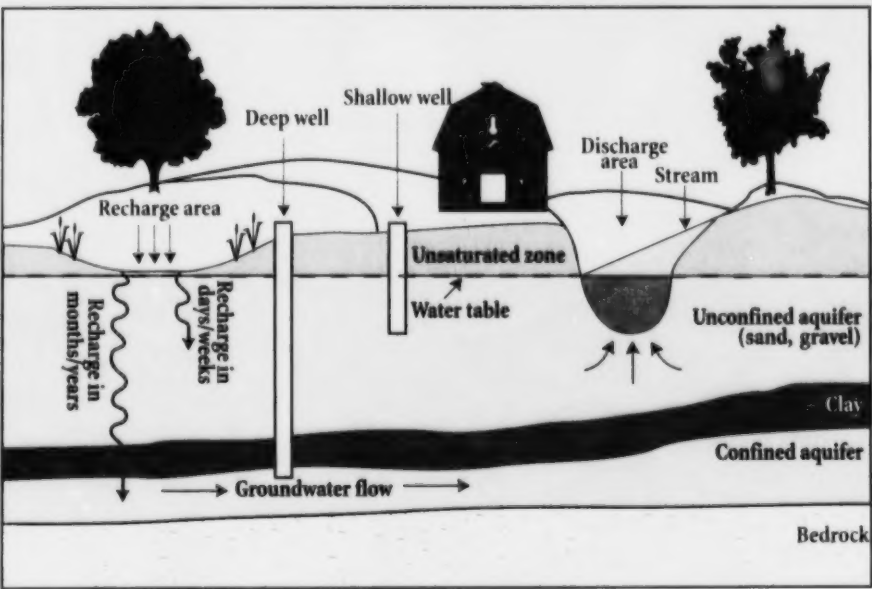
has experienced high demands from competing users of a limited resource.

Conclusion

Despite Canada's vast water resources, year-to-year variation in precipitation seems to be increasing just as rural water supplies are being used to their maximum potential. Dry years mean that reservoirs, dugouts, and groundwater aquifers are not properly recharged. Many areas must concern themselves with careful water management to ensure that enough water is available for all users on a sustainable basis over a long enough period to take account of the dry years. In the past, managing water resources concentrated on water supplies. Where water resources are limited or are unreliable, this approach is not adequate to meet the ever-growing demand for water. The current thinking in water management is to exercise control where it will be effective on the demand for water.

Strict application of the principles of demand management will place pressure on agricultural producers to use water more efficiently and to return unconsumed water to the cycle in a form acceptable to other users. Some means of demand management, such as metering and charging for water, may place heavy burdens on rural water users, especially farmers, during times of financial difficulty. However, if measures are not taken, the impact of drought years will become intolerable.

Figure 9-1
Recharge of aquifers



Using reclaimed water in Vernon, British Columbia

In the late 1960s, the Federal-Provincial Okanagan Water Basin Study concluded that phosphorus from sewage treatment plants discharging into Okanagan Lake was a major cause of the proliferation of weeds in the lake. The City of Vernon, B.C., embarked on a project to reclaim its wastewater by using it to irrigate farmland adjacent to the city. After a 6-year pilot project, a full-scale system was put into operation in 1977.

Since 1977, the irrigated land base has been continuously expanded to meet the increased wastewater flows. All the reclaimed water generated has been used beneficially for irrigation, except for three instances when the storage capacity of the reservoir was exceeded.

The reclaimed water is now used on 1050 hectares (2600 acres) south of the city. About 65% of the land is used for agricultural purposes, such as grazing and hay production; 15% is used in forestry applications such as seed orchards, nurseries, and poplar plantations; the remainder is used for golf courses and sports fields.

The new Municipal Sewage Regulations in British Columbia, which came into effect in July 1999, allow for expanded use of reclaimed water, provided proper treatment, monitoring, and quality standards are in place. The next stage is to use the reclaimed water in dual distribution systems in new residential areas. The reclaimed water will be distributed in specially marked purple lines for lawn and garden irrigation. This program will expand the life of existing potable water supplies.

E.A. Jackson, City of Vernon, British Columbia

The efficient use of water implies doing more with less. Efficiencies can be gained in all sectors, including agriculture, municipal, domestic, and industry. Chapter 3 includes several examples of ways to improve water use efficiency in agriculture, as well as the benefits of doing so, such as reductions in wastewater produced and energy consumed.

Central to a successful water conservation program are an understanding of

- the water resource itself (baseline data and monitoring)
- how, when, and why water is used (water audits and metering)
- the full cost of providing water of suitable quality and disposing of wastewater
- alternative water-efficient technologies, processes, and practices
- attitudes and values related to water and the environment.

Public education and awareness are necessary tools in implementing water conservation. However, they may need to be supplemented by provincial and federal legislation and regulations and economic incentives and disincentives, including consumption-based pricing. The Okanagan case study (p. 120) illustrates how demand management principles and water conservation are being applied to a region that

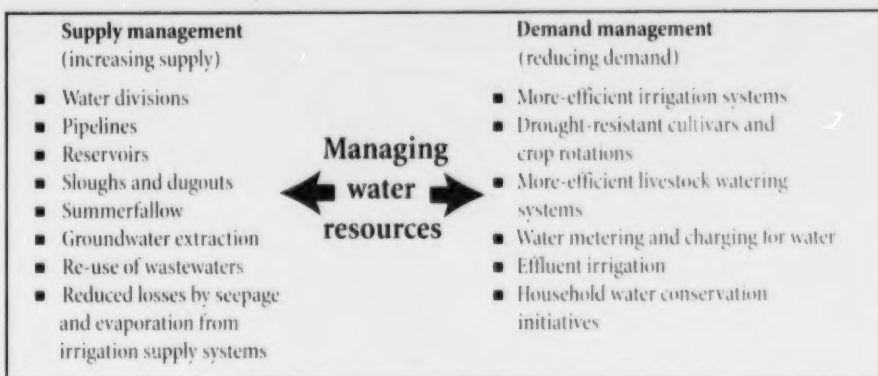


Figure 9-2
Ways to manage water resources for agriculture

has experienced high demands from competing users of a limited resource.

Conclusion

Despite Canada's vast water resources, year-to-year variation in precipitation seems to be increasing just as rural water supplies are being used to their maximum potential. Dry years mean that reservoirs, dugouts, and groundwater aquifers are not properly recharged. Many areas must concern themselves with careful water management to ensure that enough water is available for all users on a sustainable basis over a long enough period to take account of the dry years. In the past, managing water resources concentrated on water supplies. Where water resources are limited or are unreliable, this approach is not adequate to meet the ever-growing demand for water. The current thinking in water management is to exercise control where it will be effective on the demand for water.

Strict application of the principles of demand management will place pressure on agricultural producers to use water more efficiently and to return unconsumed water to the cycle in a form acceptable to other users. Some means of demand management, such as metering and charging for water, may place heavy burdens on rural water users, especially farmers, during times of financial difficulty. However, if measures are not taken, the impact of drought years will become intolerable.

Drawdown of Saskatchewan's Estevan Valley Aquifer

Boundary Power Station is a thermal generating station near Estevan, Sask., that produces one-third of the province's electricity. Historically it has relied on Boundary Reservoir for cooling water. With the major drought of 1988, followed by several consecutive years of little or no runoff, water in the reservoir reached very low levels. In a successful attempt to avoid reducing the power station's output, SaskPower installed a network of high-capacity wells in the Estevan Valley Aquifer to supplement surface water from the reservoir. Water production from the Estevan Valley was initiated in 1988 and terminated in 1994, with a peak annual production of 4900 cubic decametres in 1992. A total of 21 340 cubic decametres was produced from the aquifer.

In 1992, the new Shand Power Station began generating power. This power station was to use water from the recently completed Rafferty Reservoir, but water levels in the reservoir were too low to supply the station. Instead, a portion of the water produced from the Estevan Valley Aquifer was diverted to Shand. As a result of these withdrawals, major drawdowns occurred in the Estevan Valley Aquifer. Drawdowns reached 45 metres within the well field and just under 20 metres at distances of up to 20 kilometres.

Analysis of aquifer water levels since pumping ended indicates that the time needed for full recovery of the water level in the aquifer will almost certainly be several times longer than the production period. Recovery will be slow because of the low rate of recharge to the aquifer. In the 1960s and 1970s, several yield estimates based on limited pumping tests and aquifer geology and extent were made for the aquifer. These estimates ranged from 13 000 to 20 000 cubic decametres per year. More rigorous testing and analysis of the aquifer undertaken in the 1980s and mid-1990s estimated sustainable yields of 4000 to 6000 cubic decametres per year. Recharge rates are now estimated at 1 to 3 millimetres per year, and estimates of the sustainable yield have been reduced to 2400 to 2800 cubic decametres per year. This case illustrates that well production capabilities may greatly exceed the sustainable production rates of aquifers that are recharged slowly.

N. J. Shaheen, Sask Water

Case study

Demand management to conserve irrigation water supplies in British Columbia's South East Kelowna Irrigation District

In summer, an average of 123 million litres of water is consumed daily in the South East Kelowna Irrigation District in the Okanagan Valley. Ninety-five percent of this water is used in agriculture to irrigate about 2500 hectares of land. Domestic connections, numbering about 1400, account for the remaining 5% of the water used. In 1995, the district cooperated with the British Columbia Ministry of Agriculture and Food to run a pilot project aimed at reducing water use through universal metering and irrigation scheduling.

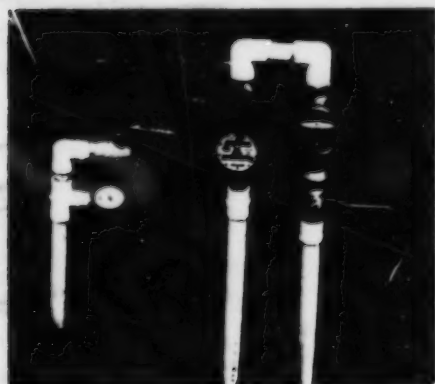
The universal water-metering program was expected to save 20% of the total amount of water used each year by making growers and other users aware of how much water they used. The water savings could be used to delay or avoid the development of new water supplies, or to support additional development in the district or expansion of irrigated agricultural lands. Water meters were purchased under the Canada-British Columbia Green Plan for Agriculture (as part of its initiative for water conservation), and the irrigation district finished installing the meters in 1996.

A 5-year irrigation scheduling project is an important part of the public education process. Scheduling programs are relatively inexpensive and appear promising as a way to optimize water use. The 10 growers participating in the project use measurements of soil water (made with devices such as

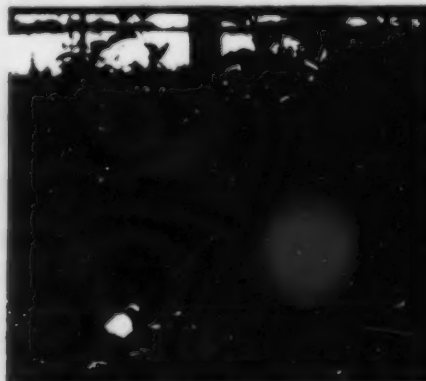
tensiometers) and climate data to schedule their irrigation. Monitoring actual soil moisture allows these farmers to apply irrigation water only as needed, resulting in more-efficient water use. All growers in the district, even those not participating in the irrigation scheduling project, were given tensiometers when their meters were installed. Since solid set and handline sprinklers are the main irrigation systems used throughout the district, additional water savings may be realized by converting from sprinklers to more-efficient drip or micro-spray irrigation.

A system for reporting water use is another component of the project. A database stores information on ownership, land use, irrigation system, soil type, and metered water use. Data on water use by each grower are collected from the meters monthly. A computer program calculates the theoretical water use for each property, using climate data and the information on soil, crop, and irrigation system for each property. A report comparing theoretical with actual water use is sent to each grower monthly. This report provides growers with timely data to assist in their scheduling. The water district manager can also use this information to direct demand management programs where they can be most effective.

*T. J. Nyval and T.W. Van der Gulik
British Columbia Ministry of Agriculture and Food*



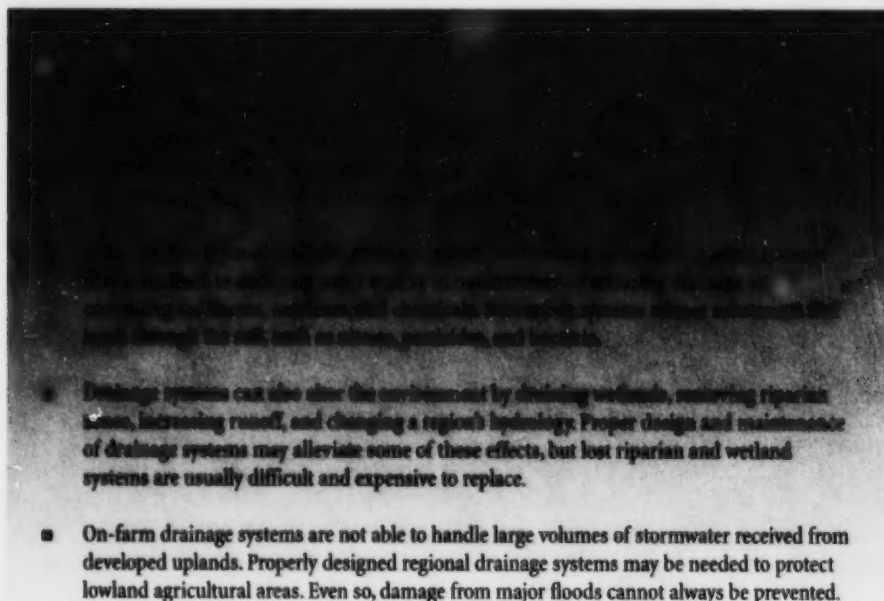
Water meter



Efficient micro-drip irrigation on apples

10. Managing Excess Water

T.W. Van der Gulik, L.H. Christl, D.R. Coote, C.A. Madramootoo, T.J. Nyvall, and T.J.V. Sopuck



Introduction

Optimal soil and water conditions are essential for agriculture. Good agricultural soils are often found in the flood plains of rivers and other regions where silts and clays have been deposited over the millennia, as well as in other areas with high water tables. These areas are subject to frequent flooding or *soil saturation*.

Drainage technology has allowed these areas to be successfully developed for agriculture in the past 100 years. The challenge in the next few decades will be to maintain sustainable and profitable agricultural production on these soils while developing drainage systems that are environmentally sensitive and integrate well with local ecosystems.

This chapter examines the benefits of draining agricultural lands by two types of artificial drainage (surface and subsurface), as well as management practices that contribute to proper drainage. It also considers the effects of drainage on water quality and the broader environment.

Benefits of draining farmland

Plants need five main things to grow—light, air, heat, nutrients, and water. All are important, but the amount of water in the soil controls soil temperature, the availability of air and nutrients, and the amount of water available for plant use. Good drainage is needed to ensure that these factors are kept at optimal levels for plant growth. Many soils are naturally well drained. The goal of artificial drainage is to remove excess water that retards plant growth and reduces productivity, but to leave adequate moisture for plant use.

Good farmland drainage provides many benefits, both on and off the farm. It enhances crop yields (Fig. 10-1) and crop value and helps to reduce the cost of production (*see* Box, p. 122). It can also contribute to protecting the environment.

When the soil is saturated (all the soil pores in the root zone are filled with water) it is easily damaged by *compaction* and *smearing* caused by farm machinery. Compaction leads to water

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Highlights

- Many agricultural areas are low lying or located in flood plains and require drainage to be profitable. Good drainage improves plant growth and crop productivity, helps to reduce soil salinity and erosion, and allows farmers a wider selection of crops and a longer growing season, all of which help to reduce the costs of production.
- There are two types of artificial drainage system: surface and subsurface. Surface systems may contribute to declining water quality in watercourses by releasing drainage water containing sediments, nutrients, and chemicals. Subsurface systems release substances that leach through the soil, such as nitrate, pesticides, and bacteria.
- Drainage systems can also alter the environment by draining wetlands, removing riparian zones, increasing runoff, and changing a region's hydrology. Proper design and maintenance of drainage systems may alleviate some of these effects, but lost riparian and wetland systems are usually difficult and expensive to replace.
- On-farm drainage systems are not able to handle large volumes of stormwater received from developed uplands. Properly designed regional drainage systems may be needed to protect lowland agricultural areas. Even so, damage from major floods cannot always be prevented.

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Improved yields with drainage in Newfoundland

The water table is often very close to the surface in Newfoundland's soils. Draining these soils helps in developing new farm fields and improving crop production.

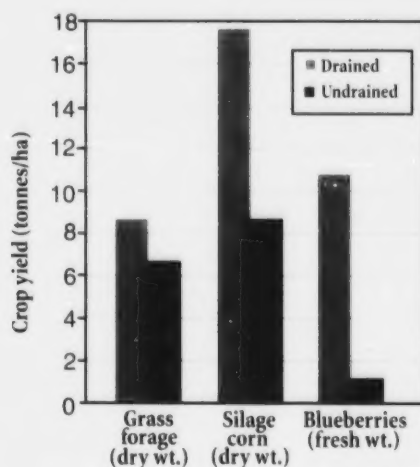
Many types of drainage systems have been tried in Newfoundland, including mole drainage on peat soils and surface ditch drainage on mineral soils with a high water table. The trenchless drain-laying plow has proved effective in installing subsurface drainage systems even in Newfoundland's stony soils. Drainage has been shown to improve forage yields by 50% on average.

Despite these advances, the benefits of drainage are not always recognized, and producers often favour land clearing over drainage to expand their operations. Until recently, no specialized subsurface drainage service was available to the agricultural industry. With so few producers interested in drainage, contractors have not invested in the specialized equipment needed to install subsurface drainage systems and maintain services.

One farmer has come up with a creative way to drain his land. Several of his fields, with shallow mineral soil and high water tables, are located between bogs. Water levels in the bogs are usually as high as, or higher than, the field perimeters or headlands. The farmer constructed a system of perimeter interception ditches that follow the contours of the field. This system produces irregularly shaped fields but has resulted in considerably improved crop yields.

G.L. Fairchild, Eastern Canada Soil and Water Conservation Centre

Figure 10-1
Effect of improved
drainage on crop yield



Source: British Columbia Ministry of Agriculture and Food, 1997

ponding on the soil surface, which may cause sealing and crusting, hindering the emergence of seedlings. When fields are not drained, the access of farm machinery to fields must be limited during the wet months of spring and fall. On the other hand, well-drained soils allow farmers to work the fields earlier in the spring and harvest crops later in the fall.

Soil erosion occurs when water fails to percolate into the soil and begins to move across the land as surface runoff. Preventing soil erosion is an important part of sustainable farming. Well-drained soils have the ability to absorb rainfall, thereby reducing runoff. The environmental benefits of reducing erosion through good drainage practices include

- less sedimentation in ditches from overland flows
- better quality of surface water (because subsurface drainage reduces surface runoff, which may contain higher concentrations of soil-bound fertilizers or pesticides).

Salinity, a condition in which there is excess salt in the soil, can also be reduced with proper drainage. Salinity is often caused by over-irrigation on soils in semi-arid areas that do not have adequate drainage. Installing subsurface drainage, together with proper water management, helps to lower the water table, which reduces salinization and returns these soils to full production (see Box, p. 124).

Most agricultural crops are adversely affected by excess water in the soil and prolonged saturation of the roots. Saturated soil conditions can reduce the availability of plant nutrients, especially nitrogen, and make the crop more susceptible to disease. Plants grown in well-drained soil are better able to withstand drought, resist plant disease, and compete with weeds. They are also more able to take up nutrients, making better use of fertilizer and reducing the amount of nutrients lost through leaching, which thus protects the quality of groundwater. Drainage also gives farmers a greater choice of crops, because land previously suitable only for crops that can be grown over a high water table may now support crops of higher value.

Good drainage also allows cover crops or green manure crops to be grown over winter. These

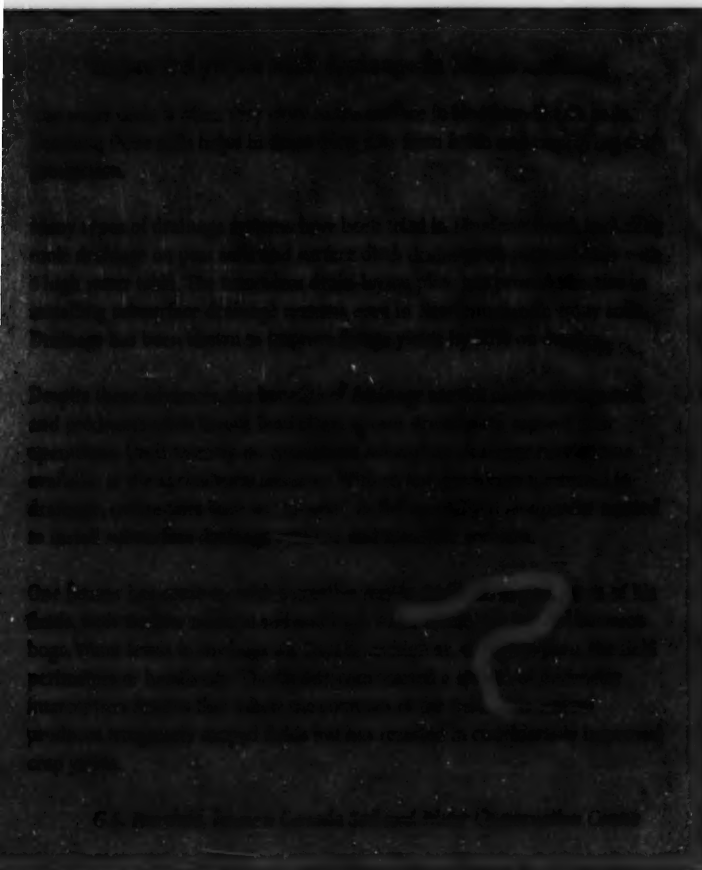
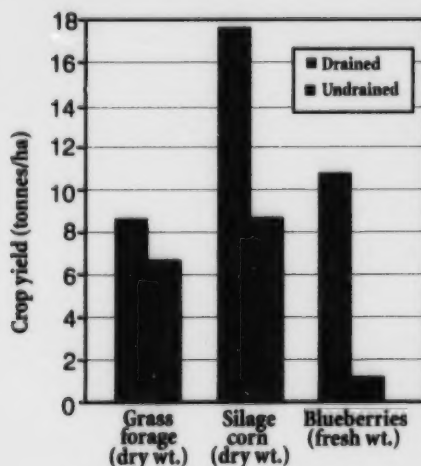


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crops protect the soil from erosion, enhance soil structure, improve soil permeability, and provide benefits for wildlife.

Where drainage is needed

Land that is wet for long periods cannot normally be farmed profitably. Under extreme conditions it may not be able to be farmed at all. Drainage of these areas is a benefit for agriculture. Whether or not drainage makes sense economically depends on

- the type of crop to be grown
- the complexity of the drainage system needed
- the impact of drainage on other land uses, such as wildlife habitat.

There are many visible clues that drainage is needed, including

- the presence of water-loving plants (e.g., reeds, willows, sedges, rushes, and coarse grass) in a field, which indicates a high water table for at least part of the year
- ponded water on the surface of the land
- high water levels in ditches and creeks near the fields
- soil salinity.

Poor crop response, crop damage, or crop loss in areas of a field may also be signs that drainage is needed.

Draining organic soils

Organic soils are those that have developed over long periods of saturated conditions, under which organic matter accumulated faster than it decomposed. These soils cover an estimated 90 million hectares throughout Canada. They include

- areas of low-fertility, acid sphagnum peat moss, such as is packaged for use in gardens and greenhouses
- areas of high-fertility black muck soils, favoured especially by vegetable growers.

These soils cannot be cultivated without improving drainage, since poor drainage is the main reason for their presence in the landscape in the first place.

Organic soils are usually drained with a combination of subsurface drains and open



Draining a saline seep



Poor drainage interfering with cultivation



Vegetables growing on drained organic soil

ditches. Pumps are often used to lift the water into a stream or outlet channel, because these soils are usually found in depressions where water collects and cannot drain naturally. Care must be taken not to over-drain these soils, or they will rapidly oxidize and shrink. Shrinking leads to subsidence, which slowly lowers the surface elevation, in turn creating more of a drainage problem. Productive organic soils can be lost completely because of over-drainage. This process can be slowed down by using drainage systems that allow the water table to be kept near the surface when crops are not growing and machinery is not on the field.

After decades or centuries, depending on the original depth and type of drainage system used, organic soils become so thin that it is no longer economic to drain and cultivate them. Depending on the type of soil materials that underlie them, they may then become permanent mineral soil areas or be abandoned to return to natural wetlands.



Subsurface drainage to reclaim saline soil in Saskatchewan using irrigation

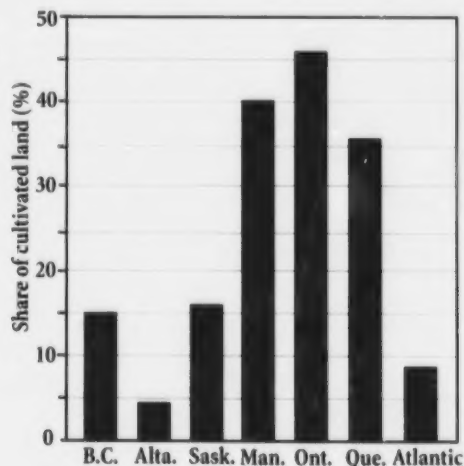
Subsurface drainage to reclaim saline soil commenced in 1986 on a 9-hectare field at the Saskatchewan Irrigation Diversification Centre. An irrigation system was used to apply leaching water in the fall of each year after harvest, beginning in 1988. The effects of this leaching on drainage outflow and effluent quality were monitored. Changes in soil salinity were monitored and soil samples were collected.

Results indicated that large quantities of salt were removed with the leaching water each year. Based on results for the top 0.75 metre of the soil profile, there was a reduction in the combined area of moderately and severely saline soils, from 62% prior to drainage installation in 1986 to only 3% in 1989, with little change after that. Dramatic improvement in grain yield occurred following the drainage installation and fall leaching. In 1995, a crop of dry beans, considered to be salt sensitive, was produced on this land with no deleterious effects. It was concluded that this area was successfully reclaimed.

T.J. Hogg and L.C. Tollefson, Saskatchewan Irrigation Diversification Centre

Because the organic components of these soils are *mineralized* under cultivation, the drainage waters from these areas are often quite rich in nutrients, especially nitrogen and phosphorus. As well, some pesticides are not retained well by organic soils and are more easily leached than in mineral soils. Thus there is a concern for the quality of streams and lakes that receive the water removed by drainage. Another concern is the destruction of wildlife habitat that occurs when these wetland soils are cleared and drained (see Chapter 7).

Figure 10-2
Share of cultivated land
that has improved drainage
in Canada



Source: Statistics Canada, 1986; Shady, 1989

Drainage systems

The design and installation of a good drainage system requires information on soils, crops, climate, and topography. Agricultural drainage often relies on a combination of surface and subsurface drainage systems. The share of Canadian cultivated land having artificial drainage is shown by province in Figure 10-2.

Surface drainage

Surface drainage systems remove water from the soil surface but are not usually designed to lower the water table in the soil profile. In some cases, this type of drainage system may be enough to allow the field to be farmed.

Shallow, open ditches are often used to drain depressions in a field that collect surface runoff. Shallow ditches can remove surface water from large areas that have been graded and leveled. Deeper ditches are used to intercept overland flow and seepage, preventing the water from entering the farm. Field ditches normally discharge water to larger channels, which in turn convey runoff to watercourses, rivers, and lakes.

Surface drainage systems have several advantages. They have low initial costs, carry large volumes of water, remove surface water rapidly, and are easy to construct. However, they do not solve problems related to soil saturation caused by a high water table. Also, the installation of ditches results in the loss of some farmable land and an increased vulnerability to soil erosion. Maintenance costs can be very high.

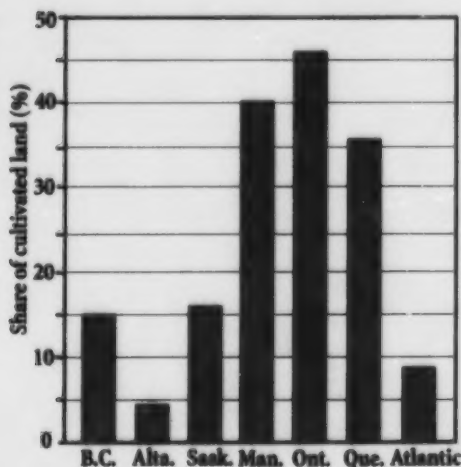
Subsurface drainage

Subsurface drainage is designed to improve crop production by lowering the water table. Perforated drain pipes are installed below the soil surface to collect excess water and convey it to a gravity or pump outlet. Outlets for subsurface drainage systems are often provided by regional drainage systems that use pumps, dykes, and deep ditches. Subsurface drainage systems provide good control of the water table and drain an area uniformly. However, they are more expensive to install than surface drainage systems.



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Subsurface drains can also be used as interceptor drains to control the seepage from groundwater discharge, from shallow lateral flow and from leaking canals. The location and depth of interceptor drains are critical to their effectiveness.

Effects of drainage on the environment

Water issues related to land drainage are growing in number, requiring a shift in water management practices. For example, groundwater supplies are being reduced as more water is withdrawn from streams and wells, and recharge is decreased by converting vegetated areas to buildings, pavement, and other impervious uses.

The number of high-intensity convection storms during the summer months may be growing as a result of climate change (see Chapter 11). These storms provide the same amount of monthly rainfall, but at a rate that lets less water infiltrate the soil. As a result, flash flooding or high runoff events in localized areas may occur.

Artificial drainage has many benefits but is also known to contribute to environmental change and sometimes degradation, including

- poor-quality drainage effluent and contaminated receiving waters in some instances
- degradation of riparian zones
- loss of wetlands
- changes in hydrologic flow paths (the way water moves through the landscape), which can increase total runoff.

Water quality

The hydrology and transport mechanisms governing how pollutants move from artificially drained soils are complex. Hydrology varies with conditions that existed before drainage improvements, as well as several other factors, such as

- land use
- type of drainage (surface vs. subsurface)
- management practices
- soils
- site conditions
- climate.

The effects of land drainage on water quality are not easily measured. Even so, some studies have shown that, compared with natural conditions, land drainage combined with a change in land use for agricultural purposes may cause an increase in peak surface runoff and losses of sediment, nutrients, and agricultural chemicals. However, other studies have shown that subsurface drainage can reduce downstream flooding.

Surface systems

Water running off the soil surface often erodes the soil and carries fine particles with it. Organic nitrogen, phosphorus, and some pesticides stay bound to these particles and move into the drainage water. For this reason, drainage water in surface drainage systems

- contains higher amounts of sediment, nutrients, and agrichemicals than drainage water from subsurface systems
- contributes more to waterway pollution and the deterioration of aquatic habitats.

Subsurface systems

Although subsurface drainage systems usually improve the quality of water leaving farmland, they can contribute to water pollution because of

- the large volumes of drainage water they transport out of farmland into watercourses
- nitrate leaching, which brings greater amounts of nitrate into subsurface drainage water
- transport of pesticides from soil to stream by leaching into drainage waters.

The manner in which water flows to drains has a direct impact on the distribution and concentration of nitrates throughout the soil profile. Preferential flow through cracks, large pores, and *biopores* (e.g., worm holes) can be a major pathway for water to move to subsurface drainage systems. Best management practices are



Laying drainage pipe



Outlet of a tile drain

needed to minimize the impact of these flows to drainage systems. For example, uniform tillage or cultivation of the soil surface prior to applying soil amendments or pest control products may help to block these pathways, reducing the risk of direct discharge of nutrients or pesticides to surface water through the drainage system. Application methods and the timing of the application of soil amendments such as mineral fertilizer, animal manure, and pesticides directly affect concentrations of nitrate, ammonium, phosphorus, and bacteria in drainage waters.

Sediment

The movement of sediment as a result of agricultural drainage is influenced by such factors as

- the type of drainage improvement
- site topography
- soil type
- land use before and after drainage improvements
- cultural practices.

The general consensus supported by international research is that increased sedimentation following artificial drainage is temporary, returning to near pre-drainage levels once exposed soil is revegetated and stabilized. Some increase in sediment movement may persist due to higher rates of post-drainage surface runoff. Subsurface drainage systems may reduce sedimentation under some conditions. Projects conducted at

Table 10-1
Runoff and soil loss from subsurface-drained and undrained sloping land at Matsqui, B.C., 1983-1984

Average (fall to spring)	Drained	Undrained
Rainfall (mm)	1625	1625
Measured runoff events	6	31
Rainfall as runoff (%)	2	19
Soil loss (t/ha)	0.1	26.7

Source: British Columbia Ministry of Agriculture and Food, 1984.

Matsqui, B.C., showed that subsurface drainage can reduce the amount of sedimentation and soil loss (Table 10-1).

Nutrients and chemicals

As land is managed more intensively following improved drainage, more nutrients and chemicals are often used. In turn, the amount of these substances leaching into drainage systems and moving from farmland into the broader environment grows. The nutrient that leaches particularly easily is nitrate.

The following examples of research findings reflect the loss of nutrients and chemicals into tile drainage water:

- In a 1987 Quebec study, concentrations of nitrogen in drainage water from corn and barley fields exceeded 40 milligrams per litre on some sampling dates during the spring and fall.
- In a 1974 study in Ontario, the combined effects of fertilization and land drainage were observed to increase phosphorus losses by four to five times and nitrate losses by 40 to 50 times on cropped muck (organic) soils compared with uncropped and undrained soils.
- A 1974 Quebec study estimated that up to 3% of the total atrazine applied on fields was lost to tile drainage water, resulting in atrazine concentrations of up to 27 micrograms per litre in samples from the Yamaska River (the Canadian drinking water guideline is 5 micrograms per litre).
- In a 1991 study in Quebec, metribuzin levels of up to 3.5 micrograms per litre were detected in drain water from tile-drained potato fields (the Canadian drinking water guideline is 80 micrograms per litre).
- Pesticides have been detected for short periods in waters discharging from New Brunswick tile drainage systems at concentrations ranging from 0.1 to 20 micrograms per litre.

Riparian zones

In the past, waterways have been straightened to hasten the movement of water off the agricultural landscape, creating some highly productive agricultural lands. In the process, the effects on

riparian zones—the land that immediately borders watercourses—have been significant.

Drainage channels may be sized and configured in a way that results in erosion of the banks and loss of bank vegetation. As a general rule, when water velocity doubles, its erosive power increases fourfold and its capacity to carry sediments increases by 64 times. Eroded sediments are eventually deposited in wetlands, lakes, or river pools, reducing channel capacity and affecting fish habitat (see Chapter 7).

Hydrology

Hydrology relates to the distribution and circulation of water in the environment—on and under the earth's surface and in the atmosphere. Drainage improvements usually accompany changes in land use to accommodate agriculture, so it is difficult to separate the effects of these two factors on hydrology.

In some cases these changes have resulted in increased rates of peak runoff. In the late 1970s, effects of clearing and draining flat, poorly drained soils for agricultural use were studied. Results showed that agricultural development using only surface drainage increases the annual outflow of water by 5 to 10%. Subsurface drainage may increase annual outflows but can also reduce peak outflows during storm events by as much as 20% (because drained soil has the capacity to store some of the storm water, thus reducing runoff).

Managing drainage

Managing drainage involves both good design and proper maintenance of drainage systems. Good design looks at the whole watershed, assessing the effects of development on the movement and volume of water involved and accounting for the needs of agriculture and other activities. Good maintenance of agricultural drainage systems considers both on-farm needs and environmental protection.

Role of wetlands

Watershed management has often not appreciated the benefits wetlands can provide, and drainage

to improve land for agricultural purposes has led to substantial loss of wetlands (see Chapter 7). Wetlands are a valuable component—hydrological, biological, chemical, and physical—of a watershed and are needed to sustain many ecosystems. Integrating wetlands into drainage networks is an important component of sustainable water management in a watershed.

Restored wetlands can remove 90 to 100% of suspended solids, 90 to 100% of *biochemical oxygen demand* (BOD, a measure of decomposable organic content), 65 to 100% of total phosphorus, and 80 to 90% of total nitrogen from runoff. However, at certain times of the year, wetlands can release some of the nutrients back into streams. Watersheds with 5 to 10% of their area as wetlands can provide a 50% reduction in peak flood period compared with watersheds that have none.

Wetlands can be used as a way of conserving water in the watershed. Restoring them takes years but usually requires less water than often believed. Drainage practitioners, experienced in managing hydrologic systems, have a key role to play in the emerging field of incorporating wetland restoration into land drainage practices.

Stormwater management

Land development creates large areas of *impervious cover*—areas, such as roofs and pavement, that cannot absorb rainfall. As uplands are developed and forests are removed, these lands are less able to retain water, and a greater volume of surface runoff reaches the lowlands. This increased runoff puts greater pressure on lowland drainage systems unequipped to handle the greater flow. In recent years, rainfall events have increased in intensity, adding to the volume of water that reaches agricultural lowlands. Because agriculture is often carried out in the flat and fertile lowlands of a watershed, farms are increasingly affected by this runoff. Flood conditions put farms at risk of losing valuable crops, livestock, machinery, and structures.

Impervious surfaces continue to expand in agricultural areas too (e.g., barns, feedlots, and greenhouses), further limiting the capacity of soils to absorb water. Drainage systems that work too efficiently in getting water out of the upper watershed add to peak flows downstream during

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Flood control in the Serpentine–Nicomekl lowlands of British Columbia

The Serpentine–Nicomekl watershed encompasses about 335 square kilometres in the municipalities of Surrey, Langley, and Delta, B.C. A large lowland area (65 square kilometres) in this watershed is subject to frequent flooding because of its low elevation, the runoff of upland water after prolonged rainfall, and the inadequacy of the existing dike system. About 65% of the lowland is farmed, and another 6% of land now idle could be farmed. The remaining land comprises residential development, golf courses and recreational facilities, and off-farm service areas.

At the time of European settlement, the area was inundated at every high tide. Settlers cleared the land and built ditches to carry water away, and a system of dikes and two sea dams were built to protect the area from high-tide flooding. Maintained since the early part of this century by the Surrey Diking District, the dike system has proven inadequate to prevent flooding. A better diking system was needed to reduce the frequency of flooding, with the benefits of greater public safety, less property damage, enhanced aquatic habitat and wildlife, and improved drainage for agriculture.

An innovative project has now been designed with the cooperation of experts in hydrotechnology, agriculture, and environment, as well as a variety of stakeholders. The two-phase project includes completing dikes in the upper Serpentine River and Bear Creek areas, upgrading 22 kilometres of existing dikes, and installing six pump stations to improve internal drainage, a fish-rearing pond, and riparian buffer zones. The cost of the 5-year project is estimated at \$30 million, which will be shared by Surrey residents through a drainage levy.

J. Howery, Alliance Professional Services

flood events. Increased surface runoff leads to more erosion in the entire watershed and the loss of municipal structures such as culverts, bridges, and other road crossings. In extreme situations, regional populations and economies are at risk.

Farmers have the ability to control most natural flow of water onto their lands using on-farm drainage systems. However, these drainage systems cannot handle large volumes of stormwater, nor can agricultural lowlands be expected to continually serve as stormwater retention areas during times of flooding. Improved regional drainage systems are often needed in these situations (*see Box*). Regional systems have the capacity to convey large volumes of water and thus offer some measure of flood prevention. Such systems are usually constructed

to prevent seasonal flooding of farmland. However, it is often impossible to control major floods, as demonstrated in 1998 in the Red River and Mississippi River basins.

Drain maintenance

Surface drainage

Drainage ditches can be kept in good working condition with proper care and regular maintenance. A ditch allowed to become obstructed with weed growth, bushes, and sediment will not provide good drainage. Uncontrolled growth of vegetation and yearly accumulations of dead plant material promotes the deposit of silt. When cleaning operations are under way, silt barriers, such as straw bales or silt fences, prevent sediment from entering natural water courses. If the channel is habitat for fish, proper notification or approval from Fisheries and Oceans Canada or provincial environmental agencies is needed before commencing maintenance.

Excavators equipped with special ditch-cleaning buckets are a preferred way to clean ditches. Drainage outlets are clearly marked out before cleaning operations begin to avoid destroying subsurface drain outlets. Cleaning ditches from only one side leaves vegetation on the undisturbed side, helping to control erosion.

Most species of fish require cold freshwater to survive. Leaving vegetation in place or planting it on the south bank of drainage channels provides shade and maintains cool water temperature while leaving the north side clear for maintenance operations.

Subsurface drainage

Overall, a properly installed subsurface drainage system needs little maintenance. In some soil conditions iron ochre forms in the drain pipes, and periodic flushing is needed to keep them operating properly. Regularly removing sediment deposits at the outlet and trees and shrubs from near the drain pipes prevents roots and sediment from blocking the drain.

Flood control in the Fraser Valley—Musquam Indian lands of British Columbia

The Fraser Valley—Musquam extended approximately about 225 square kilometers in the municipalities of Surrey, Langley, and Delta, B.C. A large wetland area (40 square kilometers) in this watershed is subject to frequent flooding because of its low elevation, the runoff of surface water after prolonged rainfall, and the inadequacy of the existing dike system. About 40% of the land is farmed, and another 6% of land now idle could be farmed. The remaining land comprises residential developments, golf courses and recreational facilities, and off-farm service areas.

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S. Harvey, Alliance Professional Services

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Conclusion

Drainage has allowed many productive soils in Canada to be cultivated. Many of our most productive farm lands in British Columbia, southern Ontario, Quebec, and Atlantic Canada would not exist without the drainage works that have been established for over more than a century. However, in some cases drainage has contributed to the loss of wetland habitat and sometimes to declining water quality.

Drainage system design can be improved to minimize the effect on hydrology and the environment. Fertilizer and chemical management on the field can also be improved so that nutrients and pesticides are less likely to end up in the drainage system. In some situations, a return of agricultural lands to wetlands may be necessary to restore habitat and reduce the environmental impacts of drainage waters.

The management of spring runoff and storm water is a regional problem. Drainage from paved and developed land must be properly retained or channeled away from other lands (e.g., agricultural, forested, or recreational). Too often it seems that drainage water is forgotten once it leaves the drained area. Downstream land and water users, wildlife, and fish should not have to cope with increased flows of water of uncertain quality. It is the responsibility of all who manage or affect the drainage of water to recognize and control negative impacts before they occur.



Red River flood in Manitoba, 1997.

1 1. Limits on Rural Growth Related to Water

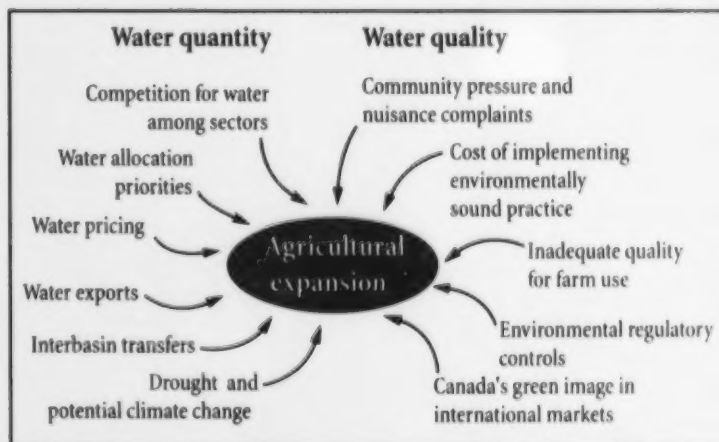
J.J. Miller, K.F.S.L. Bolton, R.C. de Loë, G.L. Fairchild, L.J. Gregorich, R.D. Kreutzweiser,
N.D. MacAlpine, L. Ring, and T.S. Veeman

- The availability of water limits the expansion of both irrigated agriculture and large-scale livestock production in western Canada. Groundwater, where available, is not always of sufficient quality for these types of farming. Intensive livestock operations also pose environmental concerns, particularly related to manure management.
- Drought limits agricultural production in some years in the semi-arid part of the Prairies and in some other areas. Droughts may become more frequent and severe in the future as a result of climate change under the enhanced greenhouse effect.
- Agricultural practices often contribute to declining water quality, and environmental liability is an issue of growing concern to farmers. Economic and environmental policy to protect water quality may limit agricultural growth, at least in the short term, until conservation farming practices are put into place to remedy this situation. Regulation has been the main instrument to protect resources, and legislation continues to impose limits on many types of rural expansion.

Introduction

Future rural growth in Canada could be limited by issues involving both quantity and quality of water (Fig. 11-1). Because agriculture occupies such a large land base and agricultural producers are themselves major users of water, the agricultural industry plays an important role in sustaining Canada's water resources. Further growth of the agricultural industry, reliant as it is on such a critical resource, will be a great challenge. Good farm management and better information about agriculture and the environment are needed to meet this challenge. This chapter examines some of the water quantity and quality issues that may limit the future growth of agriculture and other rural development.

Figure 11-1
Constraints on agricultural
expansion related to water



1.1. Limits on Rural Growth Related to Water

J.J. Miller, K.F.S.L. Bolton, R.C. de Loë, G.L. Fairchild, L.J. Gregorich, R.D. Kreutzweiser, N.D. MacAlpine, L. Ring, and T.S. Veeman

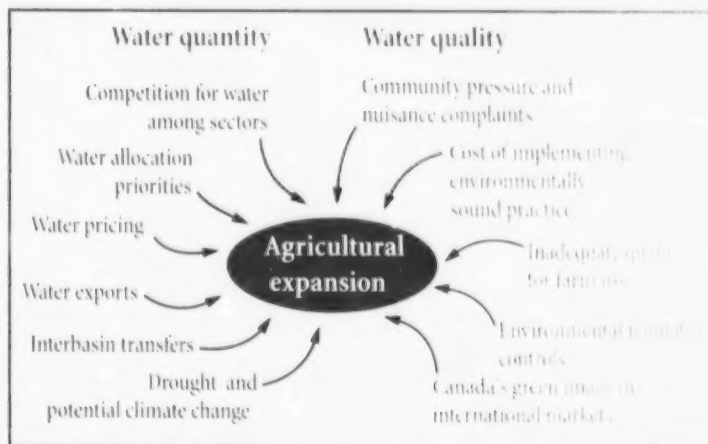
Highlights

- Competition for water among users is expected to grow as water supplies become less available, giving rise to conflict in some cases. Agriculture's chief competitors for water in terms of withdrawals are thermal power generation, manufacturing, and municipal water use. Effective solutions involve managing demand rather than guaranteeing supply.
- The availability of water limits the expansion of both irrigated agriculture and large-scale livestock production in western Canada. Groundwater, where available, is not always of sufficient quality for these types of farming. Intensive livestock operations also pose environmental concerns, particularly related to manure management.
- Drought limits agricultural production in some years in the semi-arid part of the Prairies and in some other areas. Droughts may become more frequent and severe in the future as a result of climate change under the enhanced greenhouse effect.
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Sharing the resource

Competition for water

Competition for water, both for instream and withdrawal uses, is growing and giving rise to concern about water scarcity. Competition and water use hinge on the question of supply and demand.

It is now clear that securing new water supplies to overcome water scarcity is very costly, both economically and environmentally. Large-scale interbasin transfers of water pose legal, economic, and environmental problems. By and large, problems of water scarcity and competition can be met far more cheaply by managing the demand for water rather than the supply (see Chapter 9).

Managing the demand for water is a new way in which society values and apportions water for use. Ways of achieving these changes include

- introducing more-effective pricing mechanisms for water
- reforming our water rights systems
- using technological tools for demand management.

Higher prices would reflect the increasing scarcity and value of water and not merely the costs of delivery. Reformed water rights systems would permit the eventual trading of water from low- to higher-valued uses. A particular concern is accommodating the instream flow (nonconsumptive) uses of water. Demand management tools have the advantage of being easier to implement than pricing and water rights actions.

Conflict with other sectors

Water is used by many other sectors besides agriculture (see Chapter 3). Water allocation will be an important future issue as each of these sectors expands and the demand for water, in both adequate quantity and good quality, grows. Conflict among sectors depends on withdrawal and consumptive use of water.

Thermal power generation

Thermal power generation withdraws much more water than agriculture, but the latter sector

consumes considerably more water, particularly by irrigation. Production of one kilowatt-hour of electricity requires 140 litres of water for fossil fuel plants and 205 litres for nuclear power plants. Conflict may arise between agriculture and the thermal power sector if thermal plants are located in agricultural areas.

Manufacturing

The manufacturing industry withdraws more water than agriculture, but consumptive use is higher for agriculture (see Chapter 3). The trend of many provinces to expand value-added processing of agricultural products may increase the competition for water between agriculture and manufacturing industries. For example, Alberta's provincial government issued a challenge to the agri-food sector in late 1995 "to become a \$20-billion manufacturing industry by 2005." If not properly managed, this kind of manufacturing growth has the potential to increase competition for water supplies with primary agriculture.

Municipal water use

Municipal water use and population are projected to grow in unison, possibly conflicting with agricultural growth in areas short of water. Towns and cities may compete for water supplies needed by agriculture, particularly in irrigated areas. Conflicts may also arise if water destined for municipal water use is polluted as a result of agricultural activity.

Fish and wildlife

Canada's freshwater sustains important commercial and recreational fisheries. Pollution of fishery waters as a result of agriculture could give rise to conflict between agriculture and the fisheries sector and potentially limit the growth of agriculture.

Wetlands are important habitat for waterfowl and other wildlife in rural areas, including some endangered species. Hunting and the associated economy depend heavily on preserving wetlands. A demand for more agricultural and development land in the future may exert pressure to drain wetlands, resulting in a loss of waterfowl habitat. This loss could cause conflict between rural development and waterfowl organizations (e.g., Ducks Unlimited), hunters, and environmentalists.



Saskatoon, Sask.: municipal competition for water



Recreational fishing

Water allocation

For water users in rural areas, especially farmers, who tend to be the largest consumers of water, a weak system for allocating water can become a serious problem. Even the best system cannot ensure water for all. What it can do, though, is ensure that existing or potential users of water know where they stand, providing information that is needed to make decisions regarding investments. For example, the farmer who knows there is only a small chance of receiving sufficient water in any given year is not likely to make a major investment in irrigation infrastructure. Similarly, rural communities knowing that they will have to make do with a certain amount of water are not likely to promote industrial development or types of residential development that are water intensive.

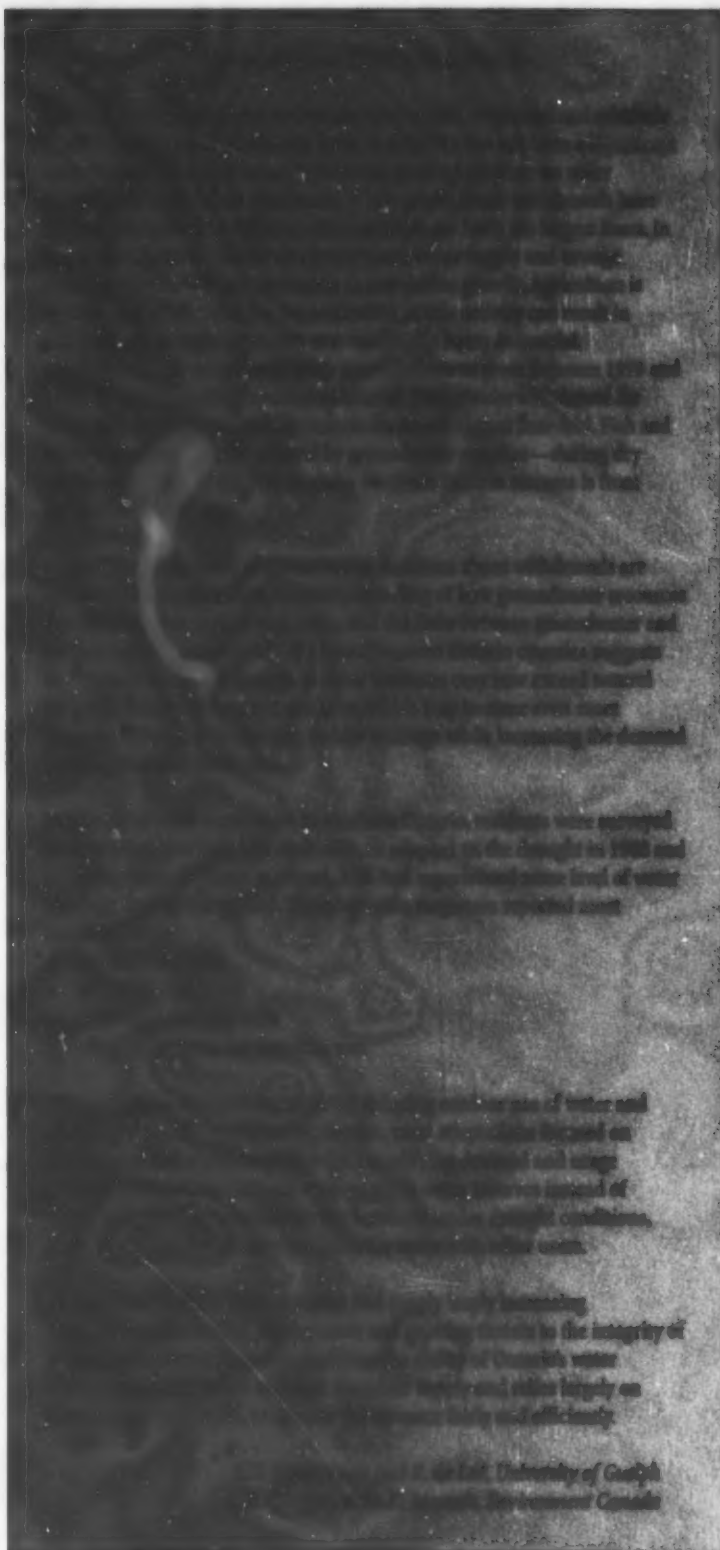
Water allocation in Canada may become more controversial and laden with conflict as competition for groundwater and surface water supplies intensifies (see Box). This competition will be aggravated if climate becomes more changeable and as concern for water quality grows.

If water becomes scarce, the nature of the allocation system can profoundly impact users (see Box, p. 10). Allocation may be particularly troublesome in provinces relying on common law principles, though areas with long-standing prior appropriation systems are not immune to these conflicts. Water allocation systems will be challenged to accommodate existing licences and new users in areas where water resources are already fully allocated.

Agricultural concerns

Expanding irrigated farmland

Alberta has most of Canada's irrigated farmland. Specialists generally agree that the land suited to irrigation in Alberta is about twice the area that can be served with the water currently available, although this figure needs to be verified. At present, most of Alberta's 13 irrigation districts are at or near their area limit. Area limits total 534 200 hectares and, in 1997, 518 000 hectares were already on the irrigation districts' assessment rolls. Thus, expansion of irrigated land is limited.



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Groundwater limits in Ontario

Conflicts over groundwater in Ontario have tended to be local and relatively small in scale, and until recently, water availability has not been a significant constraint on economic activity. However, growing pressure on water resources is being felt in rural areas. While groundwater withdrawals have not been estimated for all uses, municipalities are likely the largest users. In some municipalities reliant on groundwater, water supply and sewage treatment are becoming constraints to population growth. Agriculture is another major user, and the intensification of this activity can result in substantially increased groundwater use locally. Many industrial, commercial, and recreational water uses continue to grow. Between 1998 and 1999, for example, the permitted volume of groundwater withdrawal for water bottling in southwestern Ontario increased almost four-fold. Fish and other organisms are also affected by groundwater supplies—during dry spells up to 100% of the flow in many southern Ontario streams is from groundwater discharge.

Despite the importance of groundwater, decisions about withdrawals are often made with an incomplete understanding of how groundwater resources are distributed over time and space, and the links between groundwater and surface water. A recent study of 13 southwestern Ontario counties suggests that groundwater withdrawals in some locations may now exceed natural recharge. Relatively frequent droughts, which may become even more frequent if the climate changes, reduce recharge while increasing the demand for irrigation and other uses.

In a study of rural water users in southern Ontario, residents were surveyed to determine how they had dealt with, or adapted to, the drought in 1988 and following years. Of those surveyed, 35% had experienced some level of water shortage during that period. The adaptation responses reported most frequently were

- drilling new wells
- irrigating crops
- deepening existing wells
- trucking in water for domestic use.

Although some respondents reported reducing outdoor use of water and installing domestic water-saving devices, most adaptations focused on finding new water sources rather than modifying demand and usage patterns. Adaptations that rely on expanding water reserves instead of conserving existing sources may not be viable under drought conditions, especially where agriculture competes for water with other users.

These trends in rural water demand and supply imply increasing competition and conflict among users and growing threats to the integrity of aquatic ecosystems. They also challenge the ability of Ontario's water allocation system, which assumes abundant supply and relies largely on common law principles, to allocate the resource fairly and efficiently.

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Siting new intensive livestock operations: an example from Alberta

Intensive livestock operations (ILOs) can be large water users. Water is required not only for watering the animals, but also for cleaning barns and pens, especially in dairy and swine operations. As a result, ILOs place significant demands on water resources.

The table summarizes the annual water requirements and groundwater pumping rates (peak demand and continuous pumping with storage) for finishing feedlots and farrow-to-finish piggeries in Alberta. Large operations in this province have difficulty finding the four wells required to deliver water at rates that meet peak demand. Storage of pumped water in farm ponds or tanks is necessary for most operations.

**Annual water requirements and minimum pumping rates needed
by ILOs in Alberta**

No. of head	Licensed annual volume ¹ in cubic decameters (acre-feet)	Pumping to meet peak demand ² in litres per second (imp. gal/min)	Continuous pumping with storage ² in litres per second (imp. gal/min)
5000 steers	99 (80)	1.5 (20)	0.5 (6)
20 000 steers	333 (270)	3.0 (40)	1.6 (21)
500-sow unit	37 (30)	0.8 (11)	0.2 (2)
2000-sow unit	136 (110)	1.7 (22)	0.5 (7)

¹ Volume required by Alberta Environmental Protection, Water Rights Licensing, based on the Water Rights criteria of a unit head consumption of 45 litres (10 imp. gal.) per day per steer and 182 litres (40 imp. gal.) per day per sow unit.

² Four wells must deliver at this rate to meet feedlot and piggery demands, at a unit head consumption rate of 27 litres (6 imp. gal.) per day per steer and 91 litres (20 imp. gal.) per day per sow unit.

The areas of best groundwater yield in the province coincide with the highest rural residential density. However, odour issues are forcing new livestock operations to develop in areas with lower rural residential density, where groundwater resources may be more limiting. Thus the lack of water that limited agricultural development in the past in these less-developed areas comes to the fore again. In a study of opportunities to site new ILOs, rural residential density and existing groundwater information were mapped together. The map also accounted for the ability of the local area to produce silage for the finishing feedlot and features of the local landscape that may affect earthwork costs in building a feedlot. It was found that the number of townships that have existing wells that pump at rates that could meet the water demands of a 20 000-head finishing feedlot are limited. The same is true, but to a lesser degree, for smaller ILOs.

N.D. MacAlpine, Alberta Agriculture, Food and Rural Development

The Irrigation Branch of Alberta Agriculture, Food and Rural Development and the Alberta Irrigation Projects' Association (an umbrella organization made up of the 13 irrigation districts) are cooperating with the Prairie Farm Rehabilitation Administration of Agriculture and Agri-Food Canada to study irrigated agriculture in the irrigation districts. The results of this extensive study will allow stakeholders to better define the water requirements of irrigated agriculture and could result in the area limits being revised for some of or all the irrigation districts.

Expanding livestock industry in western Canada

The livestock industry is expanding greatly in western Canada. The hog industry is predicted to double or even triple in size. Expansion of intensive livestock operations (or ILOs, in which large numbers of cattle, swine, or poultry are concentrated in a small area) into traditional grain-farming areas may cause conflict over water quantity and quality.

Intensive livestock operations can place heavy demands on available water resources, resulting in competition with other users, especially in areas where supplies are short (see Box). As well, inadequate management of the large volume of manure produced by ILOs can lead to surface water and groundwater being polluted. The ability of these operations to manage manure is thought to be the main factor limiting expansion of the industry.

Intensive feeding operations located on dry land or beyond economical pumping distances from permanently flowing rivers or larger lakes typically rely on groundwater as their water source. In irrigated areas, most ILOs are supplied with surface water delivered by irrigation canals. An estimated 90% of water used for livestock is obtained from groundwater for most of Canada. In British Columbia, however, only 40% of water used for livestock watering is obtained from groundwater.

Even when groundwater is available, it may not be adequate because of the following concerns:

- large operations may have difficulty finding wells that deliver water at a rate

that meets peak demand, making water storage necessary

- areas of best groundwater yield often coincide with the highest rural residential density, which may limit opportunities to establish new ILOs (because of odour restrictions and minimum separation distances required)
- the quality of some groundwater is inadequate for livestock production (e.g., they are high in salts), resulting in an economic loss to the producer and an inferior product for the consumer if it is used.

Drought and potential climate change

Droughts appear to be happening more frequently in some parts of Canada. Drought causes water shortages, which in turn increase competition for water among its users (see Chapter 9). Drought also limits agricultural production by

- curbing crop growth by depleting soil moisture
- making the soil susceptible to wind erosion
- impairing livestock production by limiting water supplies.

If climates become warmer, droughts may become more frequent and severe in the future (see Chapter 9). This potential change poses grave concern for agriculture, especially in areas already dry. However, scientific study of prairie droughts has shown that droughts do not occur randomly but rather are caused by certain recognizable weather patterns. Understanding these patterns better will help in predicting droughts and planning the use of water resources (see Chapter 9).

The current potential for global warming and other climate change has other serious implications for Canadian agriculture related to the water cycle. Climate change models have been used to predict how water availability and quality could change if global warming takes place (see Box). These changes include adjustments in rainfall patterns, soil moisture, and the frequency and severity of weather events, such as thunderstorms and hail. Hydrological changes could also be seen in groundwater, runoff, and water levels.

Climate change and water for agriculture

If global warming is indeed a reality and Canada's climate changes, most areas of the country are predicted to receive more precipitation. However, water may also become less available in some areas, because higher air temperatures, longer ice- and frost-free seasons, and longer growing seasons are expected to contribute to greater evaporation and transpiration and more loss of water to the atmosphere. If the significant declines in streamflow, groundwater levels, and lake levels suggested by climate change scenarios are realized, potential for competition and conflict over water allocation will be greater. This competition could be felt between consumptive and non-consumptive users, upstream and downstream users, rural and urban areas, and arid and non-arid regions, as well as across political boundaries.

The following examples show how climate change might affect agriculture:

- In southern areas, warmer winter temperatures may lead to more precipitation falling as rain instead of snow, less snow pack, and a change in the timing and amount of spring melt and in initial soil moisture availability.
- Groundwater recharge and levels are expected to decline. Shallow aquifers will be more vulnerable initially, but if recharge remains low for long periods, regional aquifers will also be affected. Many wells would become dry and unuseable, while others would become less productive because of the loss of available drawdown. Less groundwater would be discharged to water bodies such as farm dugouts, and stream baseflow would drop.
- Low stream volumes would limit the capacity to assimilate agricultural nutrients and pesticides, and rising water temperature would further promote eutrophication and a drop in oxygen levels.
- Extreme weather events, such as droughts and floods, are expected to become more common. Convective rainfall would probably become more intense, but there may be more time between precipitation events. Precipitation may become more variable. Water shortages will be most severely felt in the Prairies and southern Ontario, increasing the need for irrigation. However, peak irrigation needs may come at a time when the water supply is dwindling.
- Higher temperatures may increase the summer stress on livestock, increasing their need for water at a time when water is least available, drying out pastures, and cutting the production of feed.

L.M. Wenger and L.D. Mortsch, Environment Canada



The Irrigation Branch of Alberta Agriculture, Food and Rural Development and the Alberta Irrigation Projects' Association (an umbrella organization made up of the 13 irrigation districts) are cooperating with the Prairie Farm Rehabilitation Administration of Agriculture and Agri-Food Canada to study irrigated agriculture in the irrigation districts. The results of this extensive study will allow stakeholders to better define the water requirements of irrigated agriculture and could result in the area limits being revised for some of or all the irrigation districts.

Expanding livestock industry in western Canada

The livestock industry is expanding greatly in western Canada. The hog industry is predicted to double or even triple in size. Expansion of intensive livestock operations (or ILOs, in which large numbers of cattle, swine, or poultry are concentrated in a small area) into traditional grain-farming areas may cause conflict over water quantity and quality.

Intensive livestock operations can place heavy demands on available water resources, resulting in competition with other users, especially in areas where supplies are short (*see Box*). As well, inadequate management of the large volume of manure produced by ILOs can lead to surface water and groundwater being polluted. The ability of these operations to manage manure is thought to be the main factor limiting expansion of the industry.

Intensive feeding operations located on dry land or beyond economical pumping distances from permanently flowing rivers or larger lakes typically rely on groundwater as their water source. In irrigated areas, most ILOs are supplied with surface water delivered by irrigation canals. An estimated 90% of water used for livestock is obtained from groundwater for most of Canada. In British Columbia, however, only 40% of water used for livestock watering is obtained from groundwater.

Even when groundwater is available, it may not be adequate because of the following concerns:

- large operations may have difficulty finding wells that deliver water at a rate

that meets peak demand, making water storage necessary

- areas of best groundwater yield often coincide with the highest rural residential density, which may limit opportunities to establish new ILOs (because of odour restrictions and minimum separation distances required)
- the quality of some groundwater is inadequate for livestock production (e.g., they are high in salts), resulting in an economic loss to the producer and an inferior product for the consumer if it is used.

Drought and potential climate change

Droughts appear to be happening more frequently in some parts of Canada. Drought causes water shortages, which in turn increase competition for water among its users (see Chapter 9). Drought also limits agricultural production by

- curbing crop growth by depleting soil moisture
- making the soil susceptible to wind erosion
- impairing livestock production by limiting water supplies.

If climates become warmer, droughts may become more frequent and severe in the future (see Chapter 9). This potential change poses grave concern for agriculture, especially in areas already dry. However, scientific study of prairie droughts has shown that droughts do not occur randomly but rather are caused by certain recognizable weather patterns. Understanding these patterns better will help in predicting droughts and planning the use of water resources (see Chapter 9).

The current potential for global warming and other climate change has other serious implications for Canadian agriculture related to the water cycle. Climate change models have been used to predict how water availability and quality could change if global warming takes place (see Box). These changes include adjustments in rainfall patterns, soil moisture, and the frequency and severity of weather events, such as thunderstorms and hail. Hydrological changes could also be seen in groundwater, runoff, and water levels.

Climate change and water for agriculture

If global warming is indeed a reality and Canada's climate change scenarios of the country are predicted to result in more precipitation. However, water may also become less available in some areas, because higher air temperatures, longer ice- and frost-free seasons, and longer growing seasons are expected to contribute to greater evaporation and transpiration and hence loss of water to the atmosphere. If the significant declines in atmospheric, groundwater levels, and in H_2O levels suggested by climate change scenarios are realized, potential for competition and conflict over water allocation will be greater. This competition could be felt between communities and both consuming water upstream and downstream users, rural and urban areas, and arid and semi-arid regions, as well as across political boundaries.

The following examples show how climate change might affect agriculture:

- In southern areas, warmer winter temperatures may lead to more precipitation falling as rain instead of snow, less snow pack, and a change in the timing and amount of spring melt and in initial soil moisture availability.
- Groundwater change and levels are expected to decline. Shallow aquifers will be more vulnerable initially, but if droughts occur for long periods, regional aquifers will also be affected. Many wells would become dry and unusable, while others would become less productive because of the loss of available discharge. Less groundwater would be discharged to water bodies such as farm ditches, and stream baseflow would drop.
- Low stream volumes would limit the capacity to assimilate agricultural nutrients and pesticides, and rising water temperatures would further promote eutrophication and a drop in oxygen levels.
- Extreme weather events, such as droughts and floods, are expected to become more common. Convective rainfall would probably become more intense, but there may be more late summer precipitation events. Precipitation may become more variable. Water shortages will be most severely felt in the Pacific and southern Ontario, increasing the need for irrigation. However, peak irrigation needs may come at a time when the water supply is dwindling.
- Higher temperatures may increase the summer stress on livestock, increasing their need for water at a time when water is least available, drying out pastures, and cutting the production of feed.

J. M. Winger and J. D. Horvath, Environment Canada

Not all changes related to global warming would be negative, and the effects on agriculture will depend on the way that farmers and industry and government policy makers adapt to the changes. The options for the agricultural sector to respond to climate change are varied and include efforts to

- reverse the buildup of greenhouse gases, such as by using tractors with better fuel efficiency or altering livestock feed to minimize methane emissions, conserving land and soil resources, and pricing food to reflect the costs of production, conservation, and restoration
- prevent or avoid the impacts, for example by shifting agriculture to useable areas in the North, producing higher-value products, introducing new crops and longer-season cultivars, and changing how water is managed
- capitalize on new opportunities, including niche marketing, new crops, and farm relocation.

Government involvement could include

- continuing research, for example to improve farming technology, create heat- and drought-resistant crop varieties, and monitor water resources
- supporting education on adaptive measures
- altering subsidy programs to better reflect climate risk
- compensating to offset production losses and difficulties with water resources.

Government controls

Governments have developed a variety of ways to promote conservation principles and, in some cases, to impose them. These methods fall into two broad categories: *regulation-based* and *incentive-based mechanisms* (also called *economic instruments*). The tools range from legislation and regulations, which require compliance with specified practices or standards or prohibit certain activities, to programs and policies that encourage and help farmers to adopt agriculturally and environmentally sound farming practices. In both cases, agricultural production may be placed under certain constraints. Public opinion and the current regulatory climate are moving toward holding polluters responsible for their activities.

Environmental liability is an issue of growing concern for farmers because of the barrier it imposes on the availability of capital, financing for operations, and adequate environmental insurance coverage.

Regulation has been the main government tool for protecting the environment. Water quality is regulated directly and indirectly through federal and provincial legislation and regulation, as well as through municipal bylaws and other provisions of local governments (e.g., districts and municipalities). When more than one level of government has authority in an environmental matter, requirements at the lower level must match or exceed the requirements at the higher level.

Federal legislation

Health Canada administers the *Canada Health Act* and is responsible for health risk assessments and, in conjunction with the provinces, for the *Guidelines for Canadian Drinking Water Quality*. A process to establish a drinking water guideline is started when a contaminant is frequently observed in water, is suspected of causing adverse health effects, or is found in high enough concentrations to pose a concern. A health risk assessment establishes a maximum acceptable concentration of the contaminant, which then undergoes a process of review and approval. In some provinces these values have the force of law, but in most they are guidelines or objectives. Research and monitoring are done by the provinces, because drinking water is considered a natural resource under provincial jurisdiction.

Inland waters and fisheries are under the jurisdiction of the provinces. However, Canada's *Fisheries Act* gives the federal government authority over marine fish and anadromous fish (ocean-going fish that spawn in rivers) in marine and freshwater environments, and interprovincial waters. The Act protects fish populations and fish habitat from pollution, prohibiting the deposition of harmful substances into fish-bearing waters or watercourses that may eventually enter fish-bearing waters. Harmful substances include suspended solids, fertilizer, manure, fuel, and pesticides. The Act also prohibits "harmful alteration, disruption or destruction" of fish habitat, defined to include "spawning grounds and nurseries, rearing, food supply and migration

areas on which fish depend to carry out their life processes." Work carried out near a fish-bearing watercourse must have the approval of Fisheries and Oceans Canada. Failure to comply with the Act may result in heavy fines or imprisonment.

Under the *Oceans Act*, administered by Fisheries and Oceans Canada, estuarine, coastal, and marine ecosystems are protected from the negative effects of land- and marine-based activities, including agriculture. This Act allows for guidelines for marine environmental quality to be developed, including those pertinent to water quality. It also emphasizes integrated management, providing for the development of management plans to protect ecological resources and ecosystem integrity and productivity in cooperation with other responsible federal authorities, such as Agriculture and Agri-Food Canada, as well as stakeholders.

The *Migratory Birds Convention Act* is the law by which Canada carries out an agreement with the United States to protect migratory birds and their habitat. Under the Act it is prohibited to release any substance, including pesticides, that is harmful to migratory birds in an area they frequent.

The *Canada Water Act* enables the federal government to collect data, conduct research, and undertake cooperative arrangements with the provinces with respect to the comprehensive planning of water resources. Activities conducted under the Act may include water quality matters.

The *Canadian Environmental Protection Act* (CEPA) is the main federal law to protect the environment. With respect to water resources, CEPA empowers the federal government to create and enforce regulations regarding toxic substances, fuels, and nutrients from cleaning products. CEPA also enables the federal government to undertake environmental research, develop guidelines and codes of practice, and conclude agreements with provinces and territories. Environment Canada administers CEPA but assesses and manages the risk of toxic substances jointly with Health Canada. The Act is currently being reviewed and amended to make pollution prevention a priority. The new Act, scheduled to be brought into force in March 2000, will require pollution prevention planning for substances declared toxic under CEPA, including

such substances used on farms. It will also include expanded regulatory powers to cover any sources of nutrients, such as fertilizers, and emissions from vehicles, including farm equipment.

CEPA does not apply, however, to aspects of substances that are regulated for environmental and human health protection under any other federal act. For example, Health Canada's Pest Management Regulatory Agency administers the *Pest Control Products Act*, including certain aspects of health and environmental assessment and regulatory decisions, as well as policy issues respecting pest control products. Once a pesticide has been registered federally, the provinces regulate its sale and use. Other examples include the *Feeds Act*, *Fertilizers Act*, *Seeds Act*, *Plant Protection Act*, and the *Health of Animals Act*, administered by the Canadian Food Inspection Agency, which provide for the assessment and management of substances (including products of biotechnology), many used and produced by agriculture, in terms of safety to the environment and human health.

The *Canadian Environmental Assessment Act* requires federal authorities, such as Agriculture and Agri-Food Canada, to conduct environmental assessment of any proposed project or activity that they fund or carry out. Environmental assessment is an important way to review potential environmental impacts of proposed projects and to make informed decisions on how to proceed to ensure that environmental concerns are addressed.

The *International Boundary Waters Treaty Act*, administered by the Department of Foreign Affairs and International Trade, authorizes the Canada-U.S. Boundary Waters Treaty, 1909. The Treaty contains a general covenant that boundary and transboundary waters shall not be polluted on either side to the injury of health or property on the other side. The Great Lakes Water Quality Agreement is a good example of Canada-U.S. cooperation under this treaty.

The *Transportation of Dangerous Goods Act* is also linked to water quality.

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Provincial legislation

All the provinces also have legislation in place (usually in the form of an environment act or water act) to protect water quality. Such legislation usually falls into the categories of land use, soil conservation, drinking water, environmental management, pesticide use, waste management, wildlife, and wildlife habitat (see Box for the type of controls that are commonly involved).

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In some cases, environmental standards are developing faster than the ability of some farmers or commodity groups to adapt. For example, expansion of the Canadian hog industry is today most limited by the lack of cost-effective technologies and methods of managing land-based manure (see Box opposite).

In other cases, agricultural practice and expansion have been impeded by public protest related to nuisance factors, such as odour or perceived pollution. Most provinces have, or are developing, right-to-farm legislation designed to protect farmers from nuisance suits. Farmers are protected if they operate according to *normal farming practice*, usually defined by a code of practice. Many provinces have boards made up of producers and other experts who investigate nuisance and pollution complaints, passing the case onto regulatory authorities only if the farmer does not take the required remedial steps (see Chapter 8). This voluntary approach to compliance allows the farmer to avoid fines and other penalties and reserves regulatory controls for those who do not respond to the remedial recommendations of their peers.

Municipal bylaws

Municipal bylaws are often designed to minimize conflict between neighbours. Those that may limit the expansion of agriculture usually relate to the siting of new farming operations, particularly intensive livestock operations. In recent years, municipalities have also assumed responsibility for drinking water in some provinces.

Regulatory constraints

Legislation and regulations specify the types of activities that may be practised or the technologies that may be used, among other



Conclusion

Governments are often anxious to address rural economic issues by proposing expansion of various developments—agricultural, residential, and industrial. It is usually assumed that physical barriers to meeting these goals are few. But water users may already be exploiting most available water in the areas targeted for this development. Data and information are often lacking, especially related to groundwater. Further intensification of agriculture, movement of city dwellers to the countryside, and expansion of value-added industries will place additional demands on available water and can be expected to produce wastes that strain water quality.

Canada is a country that has seemingly unlimited water. Although this is not true, Canadians have become so used to this idea that they seldom think that water could limit their plans. If water is not there now, then it is assumed that it can be brought in; if there's too much, then it can be drained away. Also, many people optimistically believe that human ingenuity will be up to the task of dealing with the changes that may occur if global warming takes place.

This report has shown that rural water resources are stressed in many ways, affecting almost every region of the country. Rural development is now, and will continue to be, limited by a wide variety of water issues. Questions of water quantity and quality must be at the centre of all planning for rural areas. They deserve the careful attention of farmers, policy makers, government officials, developers, and the general public.

Environmental challenges faced by Canada's hog industry

Canada's hog industry generates \$3 billion in farm receipts each year, and pork and hog exports make up \$1.5 billion or 6% of all agri-food exports. The industry is poised to expand as international markets for these products continue to grow, and Canada's position in that market is highly competitive. Of all the possible constraints on future growth of the industry, environmental issues are thought to be the most important. A growing number of applications for new or expanded sites are being rejected or held up for long periods at the municipal level because of environmental concerns.

The three main environmental challenges facing the industry, all relating to manure management, are odours, soil and water quality, and air quality. Water quality is affected when nitrates, phosphorus, and other potentially harmful substances found in manure reach groundwater, tile drainage water, and surface water as a result of inadequate manure storage, manure spills, or unsuitable methods of applying manure to farm fields. In Ontario, British Columbia, and Quebec, phosphorus levels in soil receiving hog manure are a particular concern, and British Columbia and Quebec farmers face a constant challenge in acquiring enough land for environmentally sound land application of manure. For example, in Quebec about 3000 farmers are in this situation, and at least six watersheds exceed crop needs for nitrogen and phosphorus by more than 1 million kilograms per year.

Recognizing that solutions to these environmental problems are needed if the hog industry is to capitalize on opportunities for growth, the industry and Agriculture and Agri-Food Canada (AAFC) have developed the Hog Environmental Management Strategy (HEMS) to ensure coordination in addressing environmental issues. Initiatives through HEMS include

- a \$1-million supplement to AAFC's activities to develop technical solutions to the problems facing the sector
- a \$1-million contribution from the federal government, matched by the Canadian Pork Council, to conduct research, develop technologies, and improve communications on environmental issues
- government and industry workshops at which research priorities are established and research is coordinated
- the development of a web page, "Manoware", that serves as a national information base for technical and public relations expertise to assist farmers and municipalities in addressing environmental concerns
- enhanced communications among different levels of government concerning their work to address environmental concerns.

E.R. Pidgeon, Agriculture and Agri-Food Canada



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Provincial regulatory controls on water quality

All provinces have legislation and regulations that govern water quality. These controls commonly relate to

- water treatment and sewage treatment facilities
- well drilling and construction
- testing of well water and water supply
- protection of watersheds that supply drinking water
- alterations to watercourses (including rivers, streams, brooks, lakes, or ponds)
- disposal of waste materials, crop wastes, and hazardous wastes
- handling, storage, and use of manure
- handling, storage, and use of pesticides
- septic system construction and maintenance
- installation, maintenance, and removal of petroleum storage tanks
- handling and disposal of used oil
- emergency spill procedures
- marshland or wetland protection
- land drainage
- environmental impact assessment of projects.

G.L. Fairchild, Eastern Canada Soil and Water Conservation Centre

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E.R. Pidgeon, Agriculture and Agri-Food Canada



12. Concluding Remarks

C. De Kimpe, L.J. Gregorich, and D.R. Coote

Introduction

Issues of water quantity and quality are clearly major factors in our ability to sustain agricultural activities and to protect our natural resources. This document has examined how agriculture is involved in these two issues in Canada. It has described agricultural use of water; a practical concept of water quality; the state of the water resource, both surface water and groundwater; the effects of agriculture on aquatic ecosystems; measures to maintain supplies and protect the water resource; and the limitations and pressures these issues place on future expansion of the agricultural industry and other rural activities.

Canada is often perceived as having an unlimited supply of clean water from its abundant natural water resources. However, water can be scarce or of dubious quality for many users who depend on it. Wise use of this precious resource will ensure its continued availability and quality for food production and for the needs of expanding populations and industries.

What is happening to rural water?

Water quantity

Agriculture is and will continue to be Canada's greatest consumer of water. At the same time that agricultural demand for water is growing, particularly for irrigation, other sectors are demanding more too. Competition for the finite supply of water, particularly in water-short areas such as the Prairies and the interior of British Columbia, has already given rise to conflict among users. This situation may become worse in the future under possible climate change scenarios.

Water quality

Some trends in water quality as it is affected by agriculture include the following. A general decline in the risk of soil erosion by water and wind implies a decline in the sedimentation of watercourses and water bodies by farm soil. If sedimentation continues to decrease, so too will the risk of water contamination by substances carried by soil particles, such as phosphorus, pesticides, and bacteria. However, sediment contamination continues to be a serious water quality problem at some times of the year in many regions, especially in the Maritime provinces, where wide-row crops are grown on rolling land with soils susceptible to erosion.

Nitrate associated with agricultural activities is present in nearly all groundwater underlying the main agricultural regions of Canada. Nitrate levels in groundwater supplies are generally below the Canadian water quality guideline for drinking water, but in some areas of intensive agriculture they exceed the guideline. Under prevailing management practices, residual nitrogen is accumulating in many agricultural soils under intensive production (e.g., Lower Fraser Valley, Great Lakes–St. Lawrence Lowlands). The risk of water contamination by nitrogen is increasing in these areas. In some areas of the Prairies, nitrate accumulated under the root zone may move to the groundwater if leaching conditions occur.

Pesticides are often found in both the groundwater and surface waters in Canada's agricultural regions. They are generally at concentrations well below the Canadian water quality guidelines for human drinking water but surface waters sometimes exceed guidelines for irrigation and for the protection of aquatic life. Contamination by pesticides no longer used in Canada is steadily declining, except where they are deposited here by atmospheric transport from countries still using them.

Bacterial contamination of well water is widespread. It is often related to faulty well construction. Contamination of surface waters is sometimes associated with manure either leaking from storage systems or being applied

inappropriately to farmland. There appears to be no evidence that links heavy metal contamination of water to agricultural activity.

Aquatic ecosystems

Over the years, the drainage and pollution associated with rural development have altered or destroyed some aquatic habitats, notably wetlands. This trend is beginning to be reversed as an ecosystem approach to agriculture is increasingly adopted. Some poorly drained marginal farmlands are being retired and returned to wetlands. The physical condition and water quality of streams and ditches are being restored to create useable habitat.

Why are these changes happening?

Agriculture is a large user of water, partly because water has been abundant and available at low cost. Where water remains plentiful, little incentive exists to use it more efficiently. The use of conventional farming practices—intensive tillage, applying manure to the land as a means of disposal, allowing cattle to water in streams and wetlands, applying pesticides as an insurance against weeds or insects, among others—has contributed to declining quality of both groundwater and surface water in Canada. However, increased use of conservation farming methods over the past 20 years is contributing to improved quality of many agricultural soils and their underlying and neighbouring waters. But, this improvement is still only a small step in the right direction, as many waters in areas of intensive farming are still at risk of contamination.

In Canada, the trend toward fewer and larger farms is strong. As the world's population burgeons and the demand for food and fibre grows, farmers are increasingly pressured to grow more food on a finite land base. To meet this demand, a growing number of operations are becoming more specialized in intensive livestock production or intensive horticultural or crop production. Intensified production can mean that inputs, such as crop nutrients and pesticides, and outputs, such as manure, are more concentrated in a smaller area. This situation raises the risk of

water contamination unless these substances are managed adequately. Environmental guidelines for farming are now being developed in many parts of the country to deal with this situation. Regulations placed on the agricultural industry may currently outstrip the industry's ability to meet their requirements while remaining competitive.

Why are these changes important?

Tension between agriculture and other rural water users will likely continue until a new balance is reached in the interplay of society's demand for both high-quality agricultural products and environmental protection, and the realities of farming in today's economic and global climate. With the prospect of periodic drought in the Prairies and some parts of Ontario, water use becomes a critical component in farm planning. At a grander scale, with the potential for climate change and global warming, it is possible that water quantity in the agricultural regions of Canada will change in such a way as to require changes in many agricultural practices.

Farmers follow signals that are usually beyond their control—weather and pest conditions, commodity prices, and society's preference for certain products, to name a few. To stay afloat financially in today's competitive world, they must make production decisions that are affordable. As a rule, farmers voluntarily adopt conservation practices when they improve, or at least do not diminish, the economic status of their operations. Conservation tillage is an example of such a practice. As reduced-tillage implements became more available and affordable, a growing number of farmers took up the practice, because it reduces the amount of field work needed and helps protect the soil. In other cases, the methods and technologies needed to protect natural resources are either not yet available, or are too expensive for the average farmer. Continued research is needed to develop these methods and to make them practical and cost effective for farmers. The societal benefits of protecting our water resources could lead to cost-sharing agreements among environmental groups, governments, and farmers to make the goals of water stewardship affordable.

Continued development of a conservation ethic is also needed if we are to make further progress toward sustainable agricultural practice and sustainable natural ecosystems. It is important that the role of water in the natural environment is properly valued by the agri-food sector and other users in the rural landscape, and that the rights of all users are respected by others.

What is being done to address these issues?

Water quantity will continue to be an issue in those areas of Canada where water supply is limited or people's activities compete for the resource. The growing emphasis on demand management rather than supply management is creating a climate favourable to research on technologies that use water more efficiently, such as improved irrigation systems. At the same time, public support of water metering and user-pay programs is increasing. Such programs may force farmers to rethink the economics of their water management methods. In agricultural terms, demand management involves finding ways of using existing water more efficiently, learning to farm with less water, and facing the prospect of paying for water that traditionally has been a free or low-cost resource. The conflict between users is also raising questions about reforming water rights and changing allocation practices.

Reductions in the effects of agriculture on water quality may be expected to result from the growing conservation ethic among farmers. By switching their farming practices, they can maintain productivity while posing less risk to the environment. Many conservation initiatives, such as environmental farm planning, have been led and maintained by interested farmers. Greater emphasis is placed today on community approaches to solving water problems. These actions bring the interests of farmers and other water users together in a more holistic way and focus on the wider benefits of having good-quality water.

As more is done to control erosion on the farm, water quality problems associated with sedimentation are expected to diminish. Greater use of nutrient management planning will result in a closer match between crop needs and

nutrient application, which reduces the problem of nutrients contaminating water resources. Where pesticide concentrations above guidelines have been found, use of the pesticide involved has often been restricted by the industry voluntarily or by government regulation. Some pesticides have been removed from the market. Alternative methods of pest control will assist in further reducing such problems. Proper handling, storage, and application of manure will limit the movement of bacteria and other pathogens into groundwater and surface waters.

In today's climate of limited resources, the role of government is shifting from support programming to providing the appropriate framework for industry to compete effectively in the marketplace while ensuring that the public interest is protected. In keeping with this shift, government involvement in environmental issues related to agriculture now emphasizes voluntary approaches, education and awareness building, the use of economic instruments to motivate positive change, research and technology transfer, and the use of legislation and regulation. For example, governments are carrying out research to identify farm management practices that are both economically and environmentally viable. Through information services and technology transfer, they are also seeking to expand the adoption of such practices on Canadian farms.

Governments recognize the validity of, and need for, an ecosystem approach to water issues. This approach places agriculture, with its many aspects and functions, in the context of the broader environment. To make best use of the resources, government actions are often directed at specific watersheds or regions where water quantity or quality is a concern. Regional monitoring and the national agri-environmental indicator program are being used to identify and prioritize these areas. More monitoring is desirable, but governments are generally reducing, rather than increasing, their commitments to these expensive programs. Instead, they are opting to better coordinate their monitoring efforts with universities and other organizations active in water resource planning. Continued work through partnerships will promote an integrated effort to achieve sustainable agriculture in Canada. It will ensure that the work and the costs are fairly shared, results are used to best advantage, and the voices of all stakeholders are heard.



Glossary

Additive effect Sum of the individual effects of two or more substances being added to a system (e.g., chemicals added to water).

Aggregate Sand, silt, and clay particles in soil bound together mainly by organic matter to form a small clump or clod.

Agricultural drought Type of **drought** that occurs when low soil moisture and scarce water supplies stunt crop growth, reduce crop yields, and endanger livestock.

Agrotourism Tourism related to the enjoyment of agricultural land; a type of **ecotourism**.

Aquaculture Captive rearing of fish, shellfish, and other economically important aquatic organisms under managed conditions.

Aquifer Geological bed or stratum that is far reaching and porous enough to readily yield a supply of **groundwater** to one or more wells or springs.

Available water Water held in the soil that can be used by plants; between **field capacity** and the **permanent wilting point**.

Bare-soil day Day or day equivalent (e.g., two half-days) when soil is not covered by crop canopy, residue, or snow and is thus exposed to the elements.

Baseflow Flow rate for a particular stream at a time of the year when there is no rainfall or snowmelt; usually the amount of **groundwater** discharged to a watercourse.

Benthos Animal or plant life living in direct association with the bottom material of a lake, river, or sea at any depth of water.

Benthic invertebrates Community of invertebrate species associated with the living portion of the **benthos** and forming a vital link in the food chain for higher order species.

Best management practice Agricultural practice (e.g., related to the management of soil, water, crops or livestock) that is optimal both economically and environmentally.

Biochemical oxygen demand (BOD)
Amount of oxygen in water that is consumed by micro-organisms during decomposition of a substance.

Bioaccumulation Gradual increase in the concentration of a persistent substance (e.g., **organochlorine pesticide** or **heavy metal**) in an aging organism.

Biodiversity (*also biological diversity*)
Variety of species and ecosystems on the earth and the ecological processes of which they are part; includes three components: ecosystem diversity, species diversity, and genetic diversity.

Biomagnification Cumulative increase in the concentration and toxicity of a persistent substance in successively higher trophic levels of the food chain until biologically harmful levels are reached.

Biopore Hole in the soil caused by the presence and movement of soil organisms, such as insects and earthworms, or by the decay of plant roots.

Buffer zone Strip of land between cultivated areas and natural habitat to limit the effects of farming on that habitat (e.g., streamside buffers to protect **riparian** habitat and limit the entry of soil, nutrients, and pesticides into waterways).

Canadian interim maximum acceptable concentration Water quality guideline that is temporarily established pending results of further research.

Census of Agriculture National agriculture census that records information on farm structure and economics, crops and land use, and livestock; taken every 5 years by Statistics Canada.

Code of practice Set of guidelines that producers can follow to ensure that their management practices are environmentally sustainable; sometimes built into regulations.

Compaction Condition of the soil in which soil particles are pressed together, reducing the size of the pore spaces between them.

Conservation tillage Any tillage sequence, the object of which is to minimize or reduce losses of soil and water; a tillage or tillage-and-planting combination that leaves a 30% or greater cover of crop residue on the surface.

Consume To use water in a way that does not allow it to be returned to its source (e.g., it is bound in plant or animal tissues or evaporated).

Coulee Steep ravine bordering a stream or river.

Cover crop Secondary crop grown after the primary crop or between rows of the primary crop to provide soil cover and thus limit soil **erosion** and **leaching** of nutrients.

Cross-slope cultivation Cultivation perpendicular to the direction of a hillslope, practised to control **erosion**.

Cultivar Genetically distinct plant variety, cultivated for its horticultural or agricultural characteristics.

Cyanobacteria Group of organisms related to true bacteria and belonging to the kingdom Monera; also called blue-green algae.

Decomposition Breakdown of complex organic materials into simpler materials by micro-organisms.

Demand management Managing the use of a resource, such as water, by reducing the demand for it.

Denitrification Reduction of nitrogen oxides (usually nitrate and nitrite) to gaseous molecular nitrogen or other nitrogen oxides by bacterial activity or by chemical reactions involving nitrite.

Discharge area Area in which **groundwater** comes to the soil surface.

Drainage Passage of water under the influence of gravity through soils, rocks, and other substrate materials.

Drought Prolonged period of abnormally dry weather that depletes water resources.

Dryland Type of farming that depends only on natural precipitation and soil moisture to water crops (i.e, non-irrigated).

Dugout Artificial pond, typically 4 to 6 metres deep and 2000 to 6000 cubic metres in capacity, designed to provide a 2-year water supply with allowance for evaporation losses and ice formation.

Economic instruments Incentive-based mechanisms to encourage better environmental performance, such as fees, taxes, subsidies, and grants.

Ecotourism Type of tourism promoting the natural environment and its ecological features.

Effluent irrigation Irrigation using treated municipal or industrial wastewater.

Endocrine-disrupting chemical Chemical that causes dysfunction in the hormonal systems of organisms that assimilate it.

Enhanced greenhouse effect Effect of the build-up of greenhouse gases in the atmosphere, resulting in more of the earth's radiations being trapped and potentially leading to **global warming**.

Enhancement Alteration of environmental attributes to provide improvements, usually the result of human activity.

Environmental farm plan Plan outlining environmental concerns on an individual farm, as well as steps to address these concerns; voluntarily prepared and carried out by the farmer.

Erosion Movement of soil from one location to another, mainly by wind and water, but also by tillage.

Eutrophication Natural or human-induced enrichment of **nutrients** (especially phosphorus and nitrogen) in a body of water, resulting in high productivity that may overcome natural self-purification processes; its undesirable effects include algal blooms, low oxygen levels, and reduced survival of some fish and invertebrates species.

Evapotranspiration Movement of water into the atmosphere by evaporation from the soil and **transpiration** from plants.

Fertility, soil See **soil fertility**.

Fertilizer Any substance that provides plant nutrients, such as **mineral fertilizers**, animal manure, **green manure**, and compost.

Field capacity Amount of water held by soil after it is thoroughly soaked and allowed to drain for a few days.

Flood attenuation A lessening of the occurrence, extent, or force of flooding.

Flow capacity Maximum amount of water held within the banks of a watercourse.

Functional diversity The full range of functions or ecological activities carried out by organisms and ecosystems.

Fungicide Substance that kills fungi, such as molds, mildew, and fungi that cause plant diseases.

Global warming Potential for global temperatures to rise under the **enhanced greenhouse effect**.

Grassed waterway Grassed strip of land that serves as a channel for surface runoff and is used to control erosion.

Green manure Any plant material that is plowed into the soil while still green, to serve as a natural fertilizer or soil amendment.

Groundwater Subsurface water, the upper surface of which forms the **water table** in geological materials such as soils, sand and gravel deposits, and bedrock formations; it is free to move by gravity or under a hydraulic head.

Guild Set of species that share habitat, use the same resources, or use resources in the same manner, thus having similar ecological niches or lifeforms.

Habitat fragmentation Alteration or breaking up of habitat into discrete or tenuously connected islands as a result of people modifying or converting the landscape by management activities.

Hard water Water with high concentrations of divalent metallic cations, principally calcium and magnesium bicarbonates and sulfates, that make it difficult to produce a lather with soap and that leave a scale when water is heated (e.g., in kettles and boilers).

Heavy metal Metal element with a high atomic weight, such as cadmium, chromium, cobalt, copper, lead, mercury, molybdenum, nickel, selenium, and zinc.

Herbicide Substance that kills plants, often formulated to be effective against certain species; used to control weeds on cropland, summerfallow, and rights of way.

Hepatotoxin Substance that impairs liver function.

Hydrologic cycle (*also water cycle*) Naturally occurring, solar-driven cycle of **evapotranspiration**, condensation, **precipitation**, and **runoff** of water; movement of water between the atmosphere and terrestrial and aquatic environments.

Hydrological drought Type of **drought** that occurs when a lengthy **meteorological drought** causes a sharp drop in the levels of groundwater, rivers, and lakes.

Impervious cover Land cover that prevents rain from infiltrating into soil, including roofs and pavement.

Input Something put into, or added to, a farming system, such as energy, pesticides, or nutrients.

Indicator species Species closely correlated with a particular environmental condition or habitat type such that its presence or absence can be used to indicate environmental conditions.

Infiltration Movement of surface water into soil or rock through cracks and pores.

Insecticide Substance that kills insects, often formulated to be effective against certain species; used to control insect pests of crops and livestock.

Instream use Use of water that does not require the water to be withdrawn from the source.

Integrated pest management Control of pests using a combination of techniques such as crop rotations, cultivation, and biological and chemical pest controls.

Intensive livestock operations Large-scale livestock production carried out on a relatively small land base.

Interbasin Between river basins, particularly referring to the diversion of water.

Intrabasin Within a river basin, particularly referring to the diversion of water.

Intercrop Secondary crop seeded along with the primary crop to provide enhanced soil cover, nutrients, pest control, or other production benefits.

Irrigation Application of water to a crop to augment what it receives from soil storage and precipitation.

Leaching Removal of materials in solution by water percolating through the soil profile.

Littoral zone In lakes, the zone between the shoreline and a depth of about 5 metres.

Loading Total quantity of a substance that is carried, or received, by a water body over a specified period.

Lunker Wooden platform used in stream restoration to provide cover for fish at the stream's edge.

Macroinvertebrate Invertebrate large enough to be seen without magnification.

Meteorological drought Type of **drought** that occurs when precipitation is significantly below normal over a long period.

Methemoglobinemia State of oxygen starvation produced, especially in babies, when nitrite is absorbed into the bloodstream from the digestive tract; impairment of the ability of hemoglobin to transport oxygen.

Mineral fertilizer Commercial formulation of plant **nutrients** (e.g., **nitrogen**, **phosphorus**, and **potassium**) applied to enhance crop growth.

Mineralization Conversion of an organic to an inorganic substance as a result of microbial **decomposition**.

Mitigation In environmental terms, the alleviation, remedy, or repair of damage caused by human activity.

Monoculture Cultivation of a single plant species on the same area of land for many years.

Neurotoxin Substance that impairs nerve function.

Nitrogen Key crop nutrient and water pollutant in soluble forms such as **nitrate**.

Nitrate Soluble form of **nitrogen** that is a common source of nitrogen for plants; naturally present in groundwater and surface water but sometimes elevated to pollution levels by human activity.

Nonpoint-source contamination

Contamination of water over a large area, usually when substances run off the land surface or leach through the soil profile.

Nonrenewable resource Resource whose total physical quantity does not increase significantly within a human-based time scale.

Normal farming practice Commonly accepted methods for a certain type of farming; not necessarily the **best management practice**.

No-till (also zero-tillage) Procedure by which a crop is planted directly into the soil using a special planter, with no primary or secondary tillage after harvest of the previous crop.

Nutrient Substance required by an organism for proper growth and development; key crop nutrients are **nitrogen**, **phosphorus**, and **potassium**.

Nutrient loading Total quantity of a **nutrient** carried, or received, by a water body over a specified period of time.

Nutrient management plan A farm plan that evaluates all sources of crop **nutrients** (e.g., commercial fertilizer, manure, biosolids, etc.) and allocates them to crops for maximum economic benefit and minimum environmental risk.

Objective monitoring Monitoring that responds to a known problem and usually targets specific chemicals, usually covering a small area and limited to a short time.

Oligotrophic Waters that are poor in dissolved **nutrients**, of low photosynthetic productivity, and rich in dissolved oxygen at all depths.

Organic soils Soils that have developed over long periods of saturated conditions, under which organic matter accumulated faster than it decomposed. *See also* **Peat**.

Organochlorine pesticide Organic pesticides containing chlorine, such as dichlorodiphenyltrichloroethane (DDT); known to **bioaccumulate** and **biomagnify**.

Peat Black or brown, partly decomposed, fibrous vegetative matter that has accumulated in a waterlogged environment, such as a bog.

Peer advisory program Program run by farmers to assist fellow farmers in voluntarily adopting environmentally sound farming practices.

Periphyton Complex of algae and small animals such as insect larvae that grow or move about attached to surfaces submerged in freshwater, such as rocks and plant stems.

Permanent wilting point Soil moisture content at which plants can no longer recover from daytime wilting.

Permeable Porous and penetrable by gases or liquids.

Pesticide Chemical that kills or controls pests; includes **herbicide**, **insecticide**, **fungicide**, **nematocide**, **rodenticide**, and **miticide**.

Phosphorus Key crop **nutrient** and potential water pollutant, especially of surface waters.

Photosynthesis Process by which plants transform carbon dioxide and water into carbohydrates and other compounds using energy from the sun captured by the plants' chlorophyll.

Point-source contamination Localized contamination of water, such as by direct discharge of polluted water into a stream or lake, or by accidental spills of pesticides and manure leakage into domestic wells.

Potential evapotranspiration Maximum amount of water that plants could transpire under ideal conditions, together with unavoidable evaporation from the soil.

Precautionary principle Principle that precautionary measures should be taken when an activity poses a risk to the environment or human health, whether or not sufficient scientific research has been conducted to conclusively support taking these measures.

Precipitation Any form of water, whether liquid (e.g., rain or drizzle) or solid (e.g., snow or hail) that falls from the atmosphere to the ground.

Primary production Plant biomass created and energy accumulated through photosynthesis or chemosynthesis; carried out by plants at the base of the food chain.

Recharge area Place where water percolates through the soil into **groundwater**.

Reconnaissance monitoring Monitoring that involves periodic sampling of waters over a large area and a long period, and the analysis of a wide variety of water quality parameters.

Regulation Government control by law.

Residual nitrogen The amount of nitrogen in soil beyond the needs of crops or their ability to absorb it.

Riffle Shallow area of a stream, with quickly moving water and exposed coarse sediment; favourable site for benthic communities and fish foraging and reproduction.

Riparian zone Land immediately bordering a watercourse or water body.

Runoff The part of **precipitation** and snowmelt that reaches streams by flowing over or through the ground. **Surface runoff** flows away without penetrating the soil. Groundwater runoff enters streams by seeping through soil.

Rural water Freshwater used by and affected by primary agriculture.

Salinity Condition of soil in which the soil contains excess salts.

Saline Containing excess salts; referring to soil.

Sea water intrusion Underground movement of water with high salt content into wells located near marine shorelines, often as a result of excessive withdrawals of fresh water from the well.

Sediment Soil particles that are carried in surface runoff and deposited in surface waters such as streams and lakes.

Sedimentation Deposition of **sediment** in surface waters such as streams and lakes.

Shelterbelt Line of trees or bushes planted across the prevailing wind direction to break the force of the wind.

Sink In soils, the capacity to assimilate substances and retain them or subsequently provide them as a source for above- and below-ground vegetative growth.

Slough Shallow depression containing water for at least part of the year; typically found in the Prairies.

Smearing Process by which fine-textured clay soils tend to gel when wet and disturbed (e.g., by cultivation equipment).

Soil fertility Measure of the amount of nutrients in the soil available for plant growth.

Soil moisture deficit Difference between total precipitation during the growing season, together with the amount of water that can be held in the root zone of the soil, and **potential evapotranspiration**.

Soil saturation Condition of the soil when all soil pores in the root zone are filled with water.

Soil structure Physical properties of a soil relating to the arrangement and stability of soil particles, **aggregates**, and pores.

Soil texture Relative proportions of sand, silt, and clay in a soil.

Soil tilth Physical condition of the soil as it relates to ease of tillage and fitness as a seedbed.

Subsurface drainage Underground movement of water away from an area; referring to natural or artificial systems.

Summerfallow Cropland that is not cropped for at least 1 year but is managed by cultivating or spraying for weeds; a *Census of Agriculture* category for agricultural land use.

Supply management Managing the use of a resource, such as water, by maintaining a reliable supply of it.

Surface drainage Movement of water away from an area on the soil's surface; referring to natural or artificial systems.

Surface runoff Water running off the land on the surface.

Suspended sediment Soil particles held in suspension in water.

Sustainable agriculture Way of farming that maintains the land's ability to produce over time.

Synergistic effect Interaction of two or more biotic or abiotic substances or processes with the net effect being greater than the sum of the independent effects of each substance or process.

Terrace Steplike surface topography that breaks the continuity of a slope; a device for controlling soil **erosion**.

Texture See **soil texture**.

Tile drainage System of underground perforated pipes that carry excess soil water to an outlet ditch or stream; originally made of clay tile, but mostly plastic pipe today.

Tillage erosion Displacement of soil by the action of tillage.

Transboundary Crossing a provincial or national border.

Transpiration Loss of water vapour through the stomatal openings in plants, or by evaporation from cell tissues.

Turbidity Measure of water clarity, or the degree to which water is opaque due to suspended silt or organisms.

Up- and down-slope cultivation Cultivation in the direction of a slope of a hill (as opposed to **cross-slope cultivation**).

Water allocation Process of deciding where, when, and how water resources are used or water management activities are directed.

Watercourse Moving body of water, such as a creek, stream, or river.

Water cycle See **hydrologic cycle**.

Water erosion Displacement of soil by water flowing along the soil surface.

Water quality Chemical, physical, and biological characteristics of water; fitness of water for a specific use, such as aquatic habitat, drinking water for humans, and irrigation.

Water quantity Measurements of amounts of water present in the landscape as surface water or groundwater.

Water table Zone of water saturation in soil; upper surface of the **groundwater**, found at a depth at which the pressure in the water equals atmospheric pressure.

Watermastering Allocation of water, usually according to the priority of each user.

Watershed An area of land, sometimes under forest cover, that drains water, organic matter, dissolved **nutrients**, and **sediments** into a lake or stream; the topographic boundary is usually a height of land that marks the dividing line from which surface streams flow in two different directions.

Wetland Area of land frequently or permanently inundated by surface water or **groundwater** and generally able to support vegetative or aquatic life that requires saturated or seasonally saturated soil conditions for growth or reproduction; under the Canadian Wetland Classification, there are five wetland classes, 70 wetland forms, and numerous wetland types based on vegetation.

Wind erosion Displacement of soil by wind.

Withdrawal use Use of water that withdraws it from its source and may or may not return it.

Year class Age class of fish, by year.

Zero-tillage See **no-till**.

Zero tolerance With respect to water quality, the position that no amount of unnatural substance (e.g., **pesticide**) or elevated amount of nutrient (e.g., **nitrate** or **phosphorus**) in water is acceptable.

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